



Image Science and Analysis Group
KX\Human Exploration Science Office
KAAARES



ISS Inspection Capabilities and Challenges

NASA Johnson Space Center
Astromaterials Research and Exploration Science (ARES)
Image Science and Analysis Group (ISAG)
KX/Randy Moore
<http://isag.jsc.nasa.gov/>

July 2014



ISAG Background



- The JSC Image Science and Analysis Group (ISAG) provides NASA with expertise in all areas of imaging science.
 - IS&AG homepage <http://isag.jsc.nasa.gov/>
- ISAG emerged and evolved during the Shuttle Program.
 - ISAG formed from the Crew Earth Observation image analysis capability to fulfill a STS-51L lesson learned for screening/analyzing launch/landing imagery
 - Tasks grew to include support of ISS assembly
 - STS-114 brought near-realtime mission support for characterization of ascent debris shedding and on-orbit vehicle inspection.
- ISAG expertise built and honed for Shuttle is now applied to ISS, Orion Multi-Purpose Crew Vehicle, Space Launch System, and Commercial Crew & Cargo Programs.
 - Imagery acquisition planning
 - Requirements development
 - Imagery operations and data management
 - Imagery based inspection surveys
 - 2D and 3D photogrammetric measurements
 - 2D and 3D high-precision motion tracking



ISAG Support to ISS Program



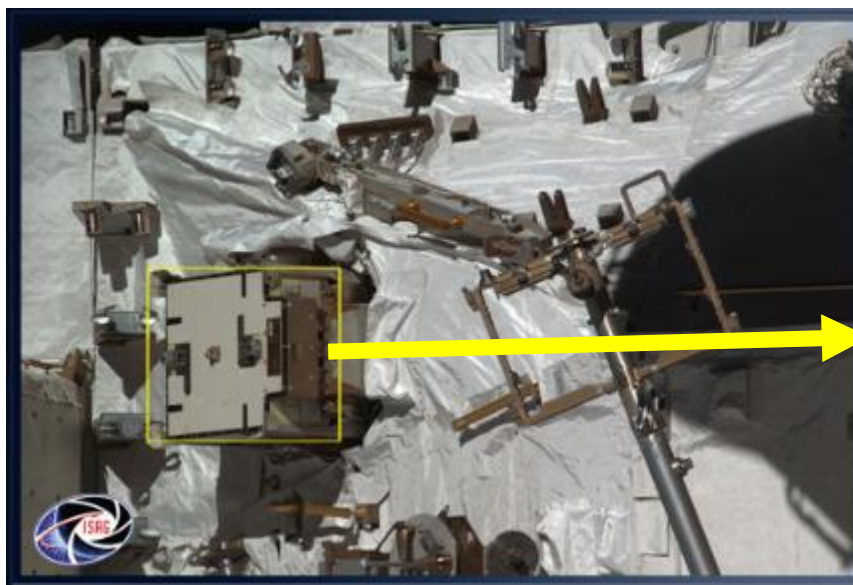
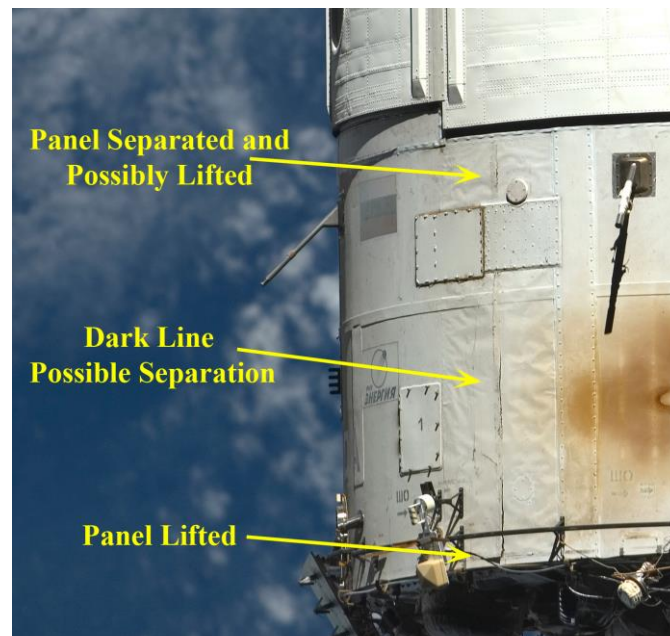
- **Primary focus is on maintaining the safety of the crew and vehicle.**
- **ISAG personnel screen downlinked imagery to:**
 - **Monitor for, and report changes in the ISS external condition**
 - **Anomalous indications**
 - **Hardware out of configuration**
 - **Detect Micro-Meteoroid or Orbital Debris (MMOD) impacts leading to:**
 - **Hardware failure**
 - **EVA sharp edges**
- **ISAG personnel assist in planning for acquiring the imagery needed to derive engineering data, supporting:**
 - **Anomaly investigation**
 - **3-D structural dynamics measurements**
 - **Clearance assessments**
 - **Verifying ISS configuration against models and requirements**
 - **Jettison trajectory calculation**



Uses and Examples ISS Inspection Imagery



Monitoring the ISS External Condition



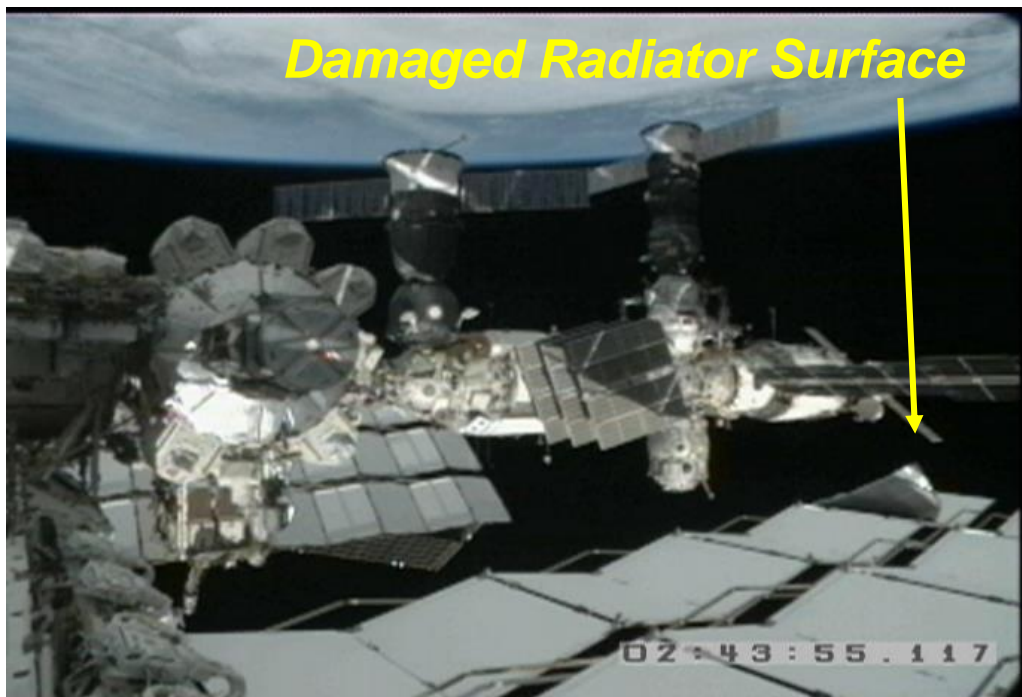


Monitoring the ISS External Condition

Increment 37 Soyuz discoloration near access panel

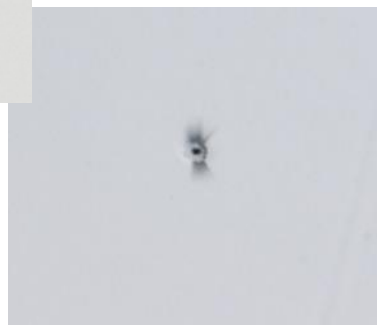
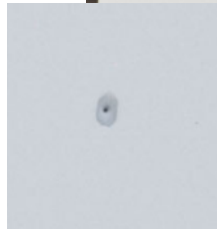
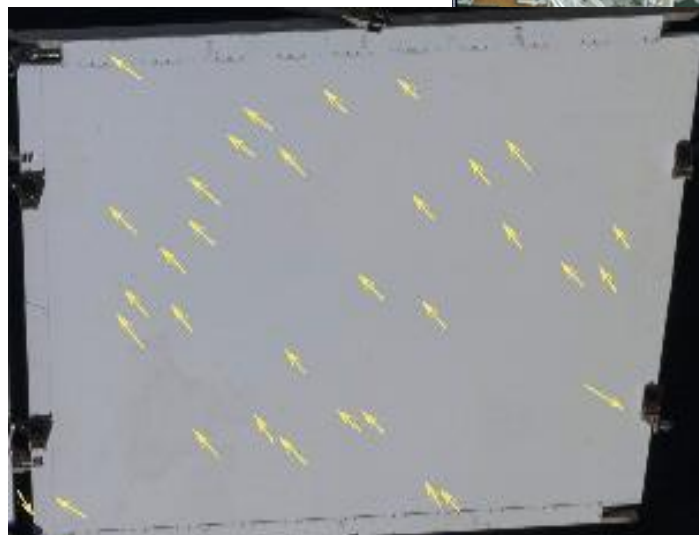
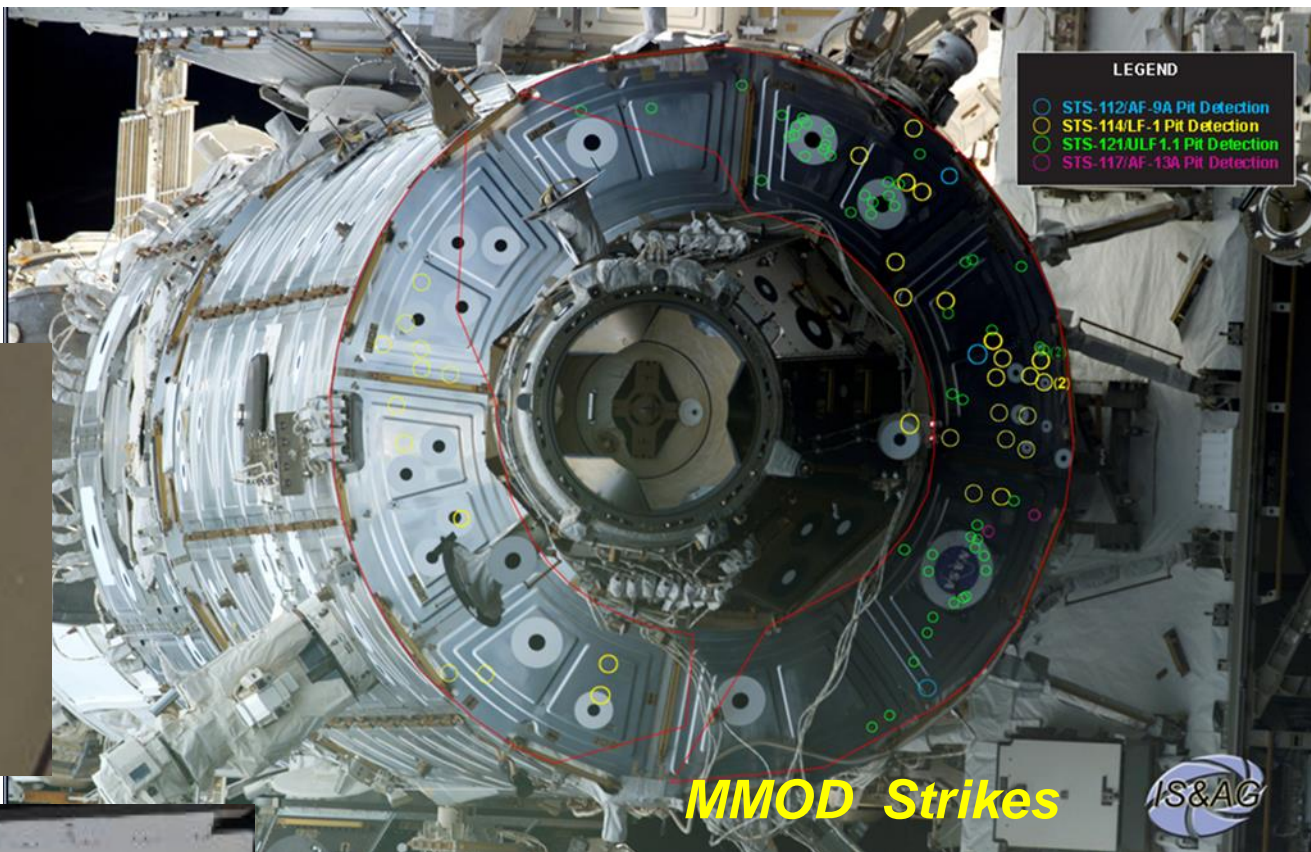
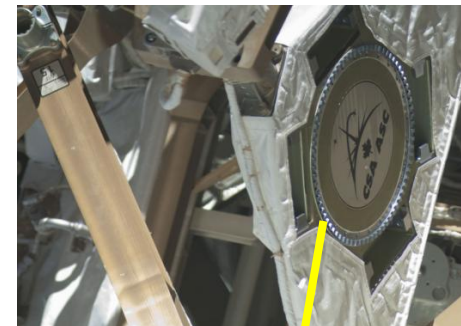


Damaged Radiator Surface





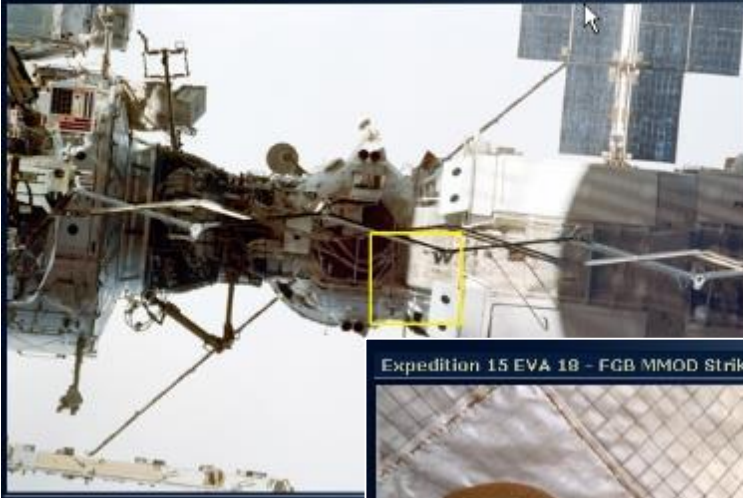
Monitoring the ISS External Condition





Monitoring the ISS External Condition

STS-114 Fly-Around Imagery - FGB Zenith Side



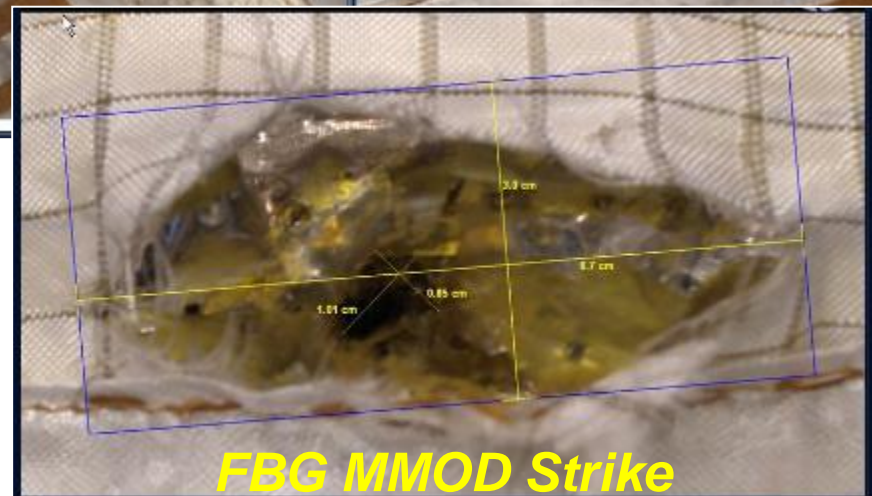
STS-114 Fly-Around Imagery - FGB Zenith Side (cropped, enhanced)



Expedition 15 EVA 18 - FGB MMOD Strike (Image ID: ISS015E10851)



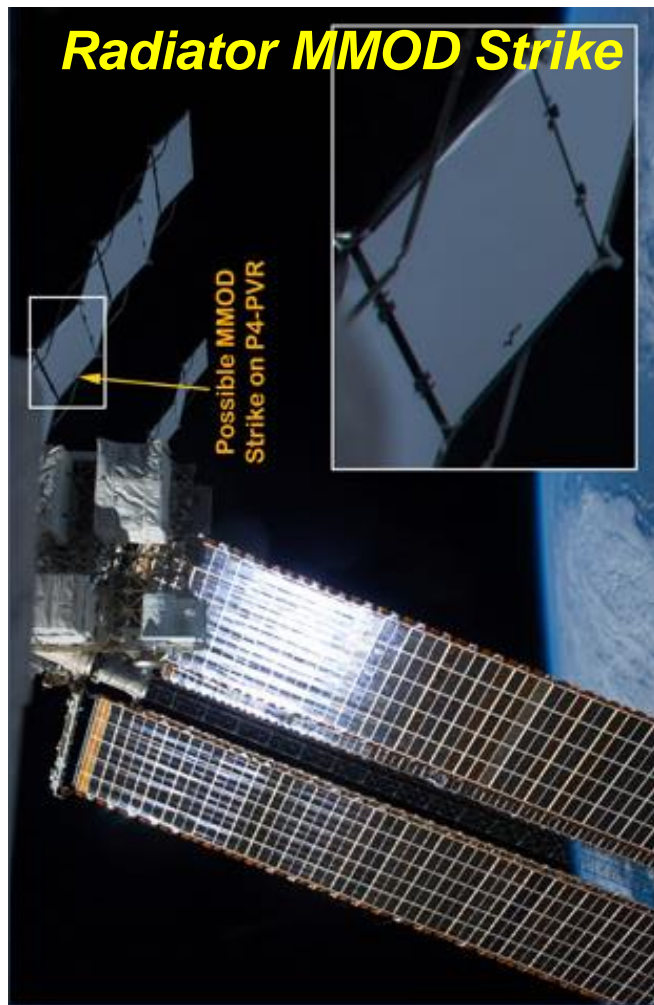
Expedition 15 EVA 18 - FGB MMOD Strike (Image ID: ISS015E10855)





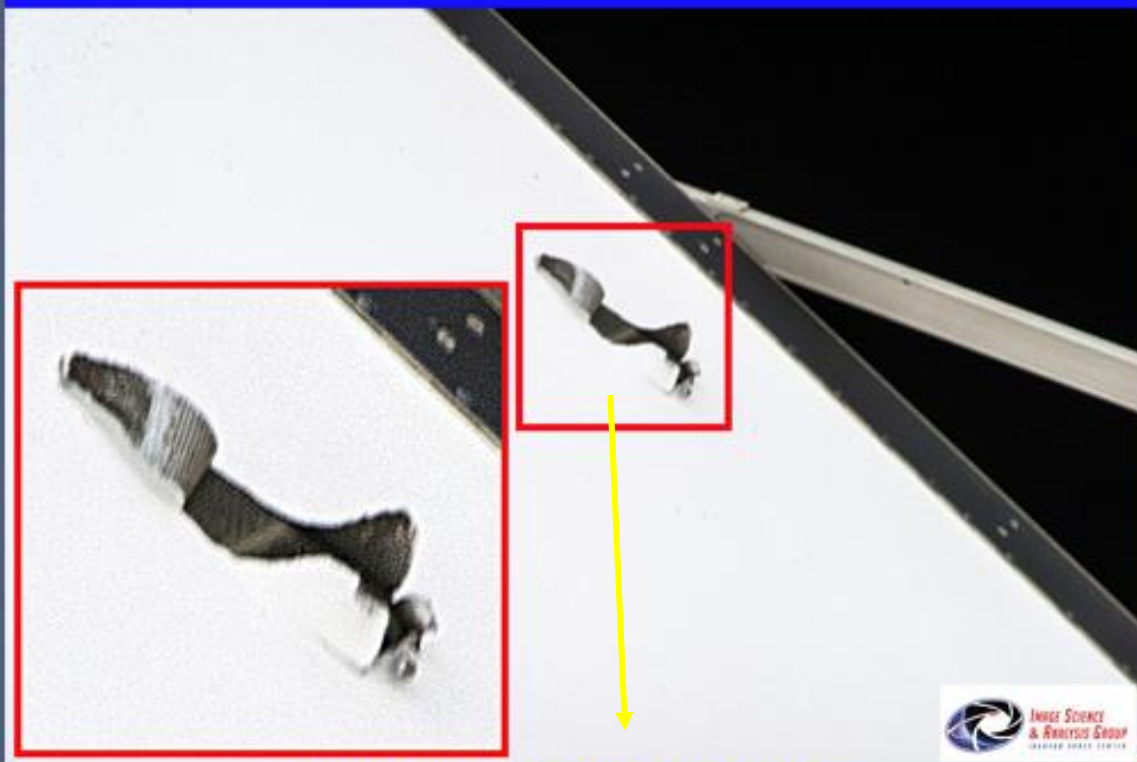
Monitoring the External Condition

Radiator MMOD Strike



Digital Camera View of The "2A" Side of Panel 3, P4-PVR Radiator

Acquired with Nikon D3s Digital Still Camera Equipped with an 800mm Lens



Imagery Captured July 5, 2014, 186/19:19 GMT

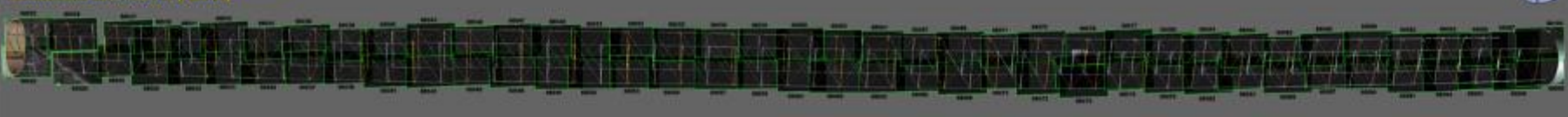
The upturned edge of the cover sheet suggest that this is likely the the exit hole of a "through the panel" impact.

Out of focus appearance is due to wave front interference caused by shooting the photo though the scratch pane.

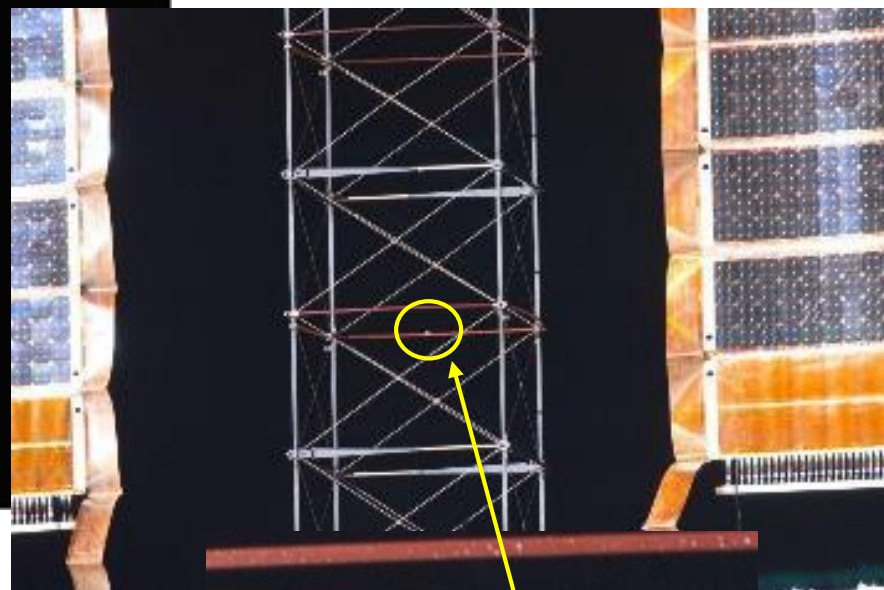
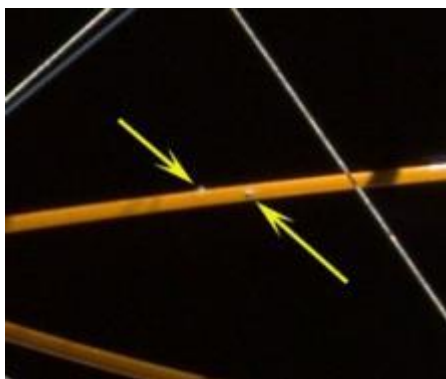
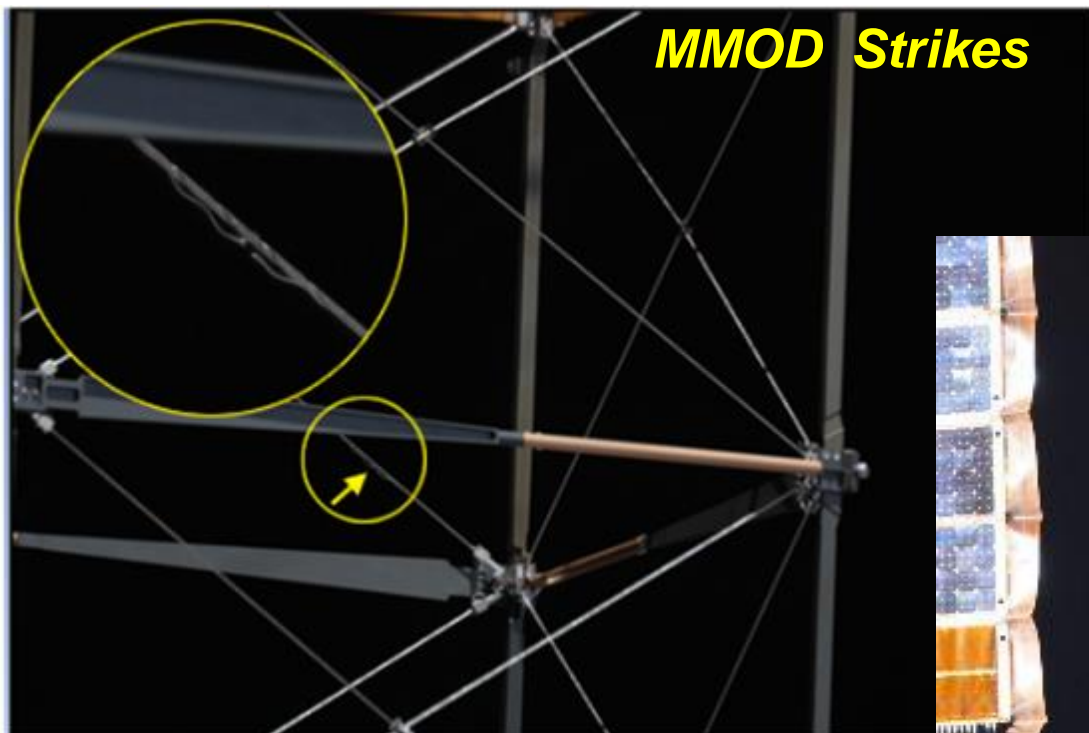


Monitoring the ISS External Condition

Photographic Survey of the P4 2A S/W Mast
STS-130/AF-20A Flight Day 11 850mm Nikon D2Xs
iss022e060922-iss022e06100 (Pass 2/2)



MMOD Strikes



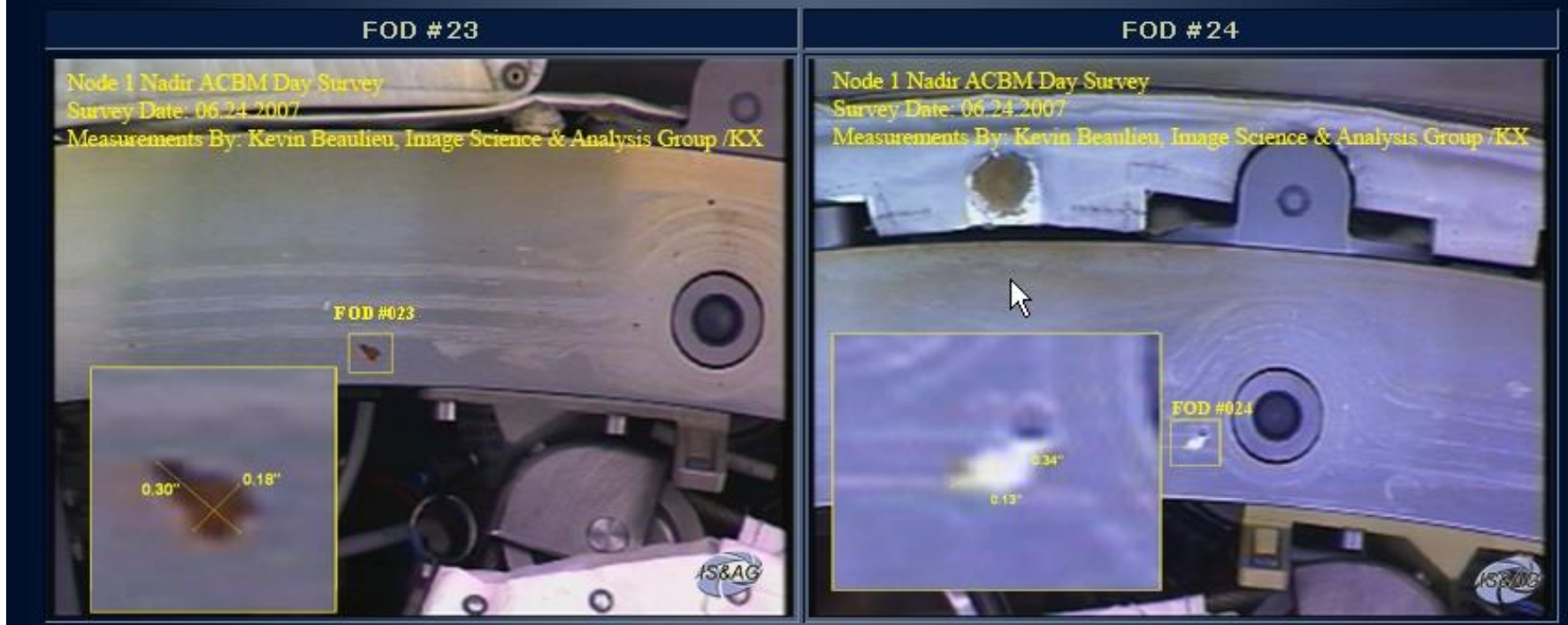
0.61 +/- 0.03 inches

0.26 +/- 0.03 inches



Monitoring the ISS External Condition

Measurements of New Foreign Object Debris (FOD) Identified by Structures and Mechanisms During the Day Survey:



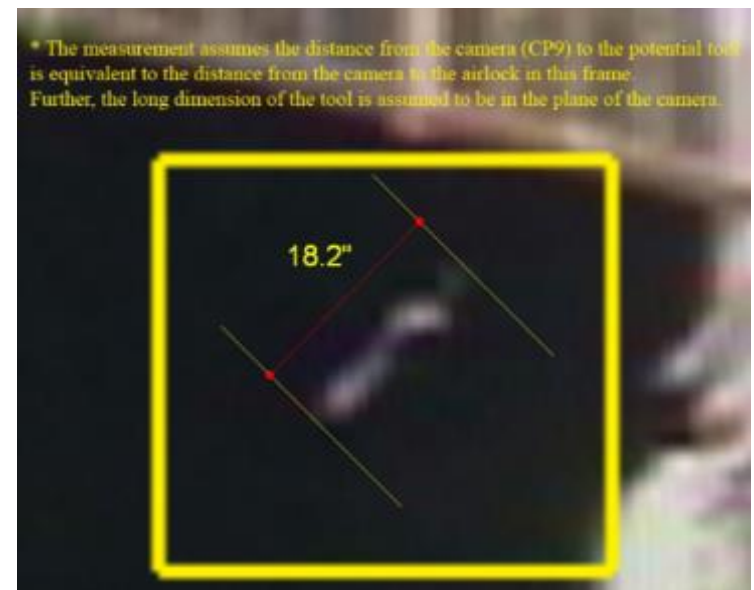
Foreign Object Debris detected in pre-berthing survey



Situational Awareness



Foreign Object Debris

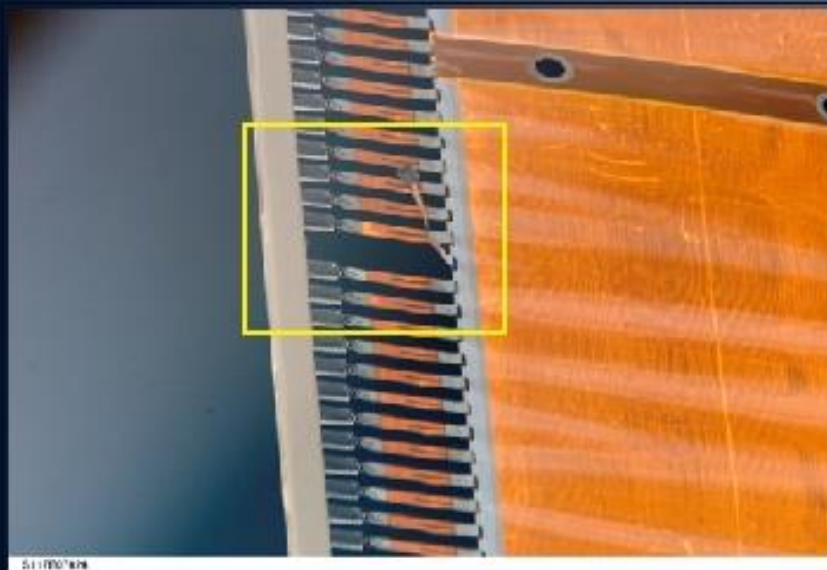




Verifying the ISS Configuration

STS-117 EVA #2 Imagery of Separated 2B SAW Leader Panel

STS-117 EVA Image (s117e07024)



STS-117 EVA Image - Enhanced (s117e07024)



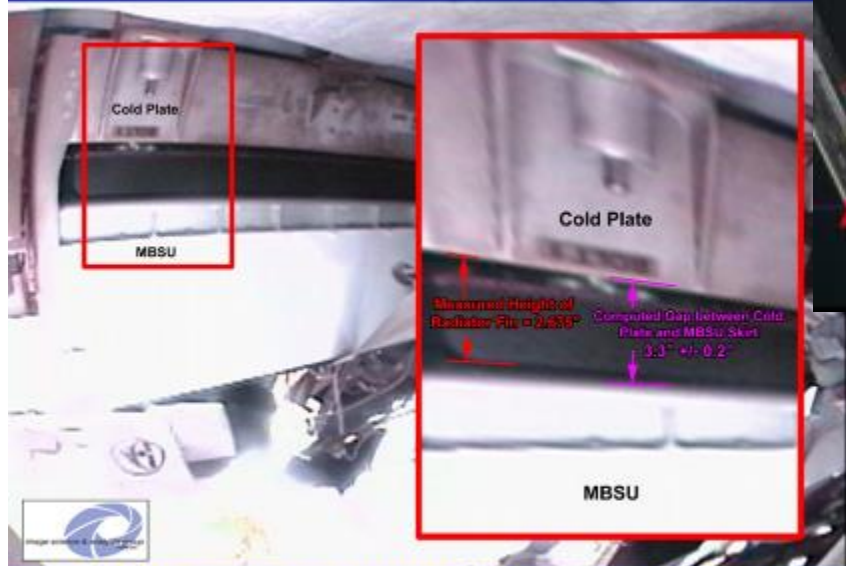
Separated Solar Array Leader Panel



Verifying the ISS Configuration

Analysis of Gap Between MBSU and Cold Plate

The following provides an estimate of the distance between the bottom of the skirt of the MBSU and the top of the Cold Plate.



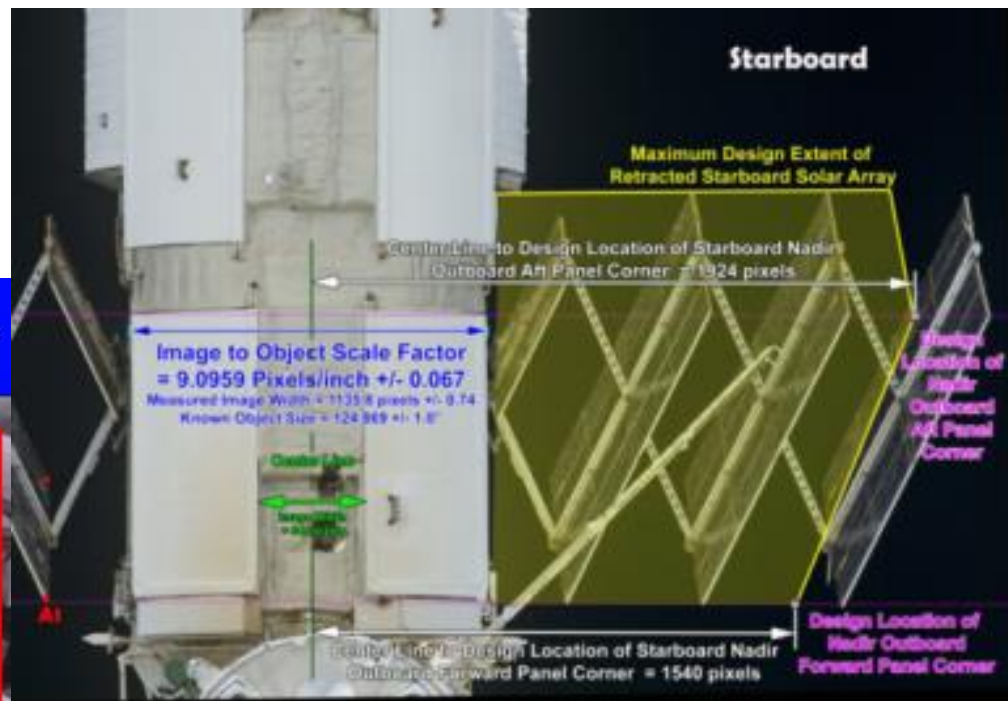
These measurements were made from WVS imagery acquired immediately prior to Airlock ingress during US EVA 18 on 8/30/12.

Scale was based upon the known height of the radiator fins off the cold plate surface which were measured on a flight-like unit on 8/31/12 by IS&AG personnel.

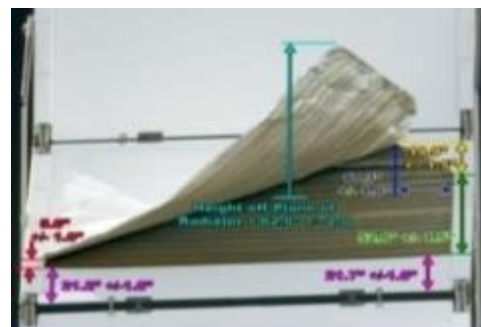
Analysis by E. Oshel, D. Osborne, G. Kilgo and D. Liddle

JSC - Image Science and Analysis Group /KX 8/31/12 Rev 1.0

**Installation gap measured from
EVA helmet video**



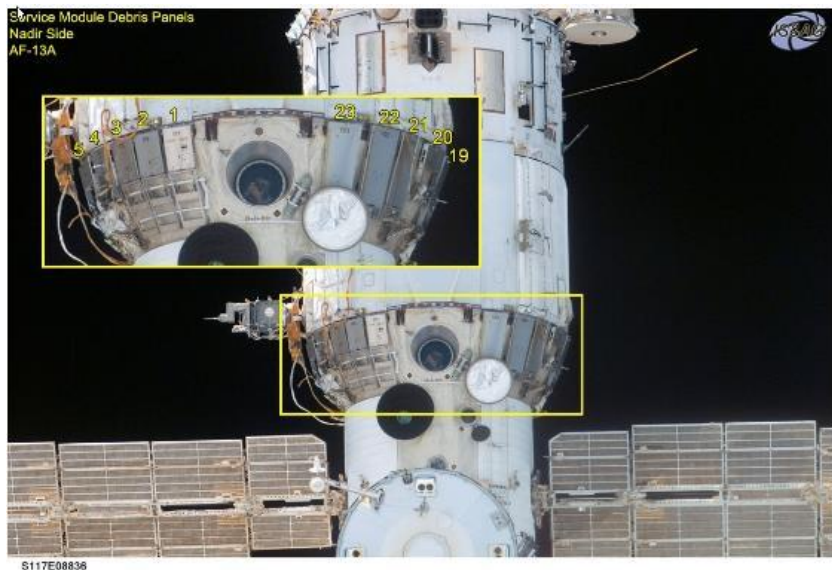
**Clearance study found FGB Solar Array
was not fully retracted**



**Periodic Inspection of
Damaged Radiator Panel**



Visual Documentation



Service Module Debris Panel Installations

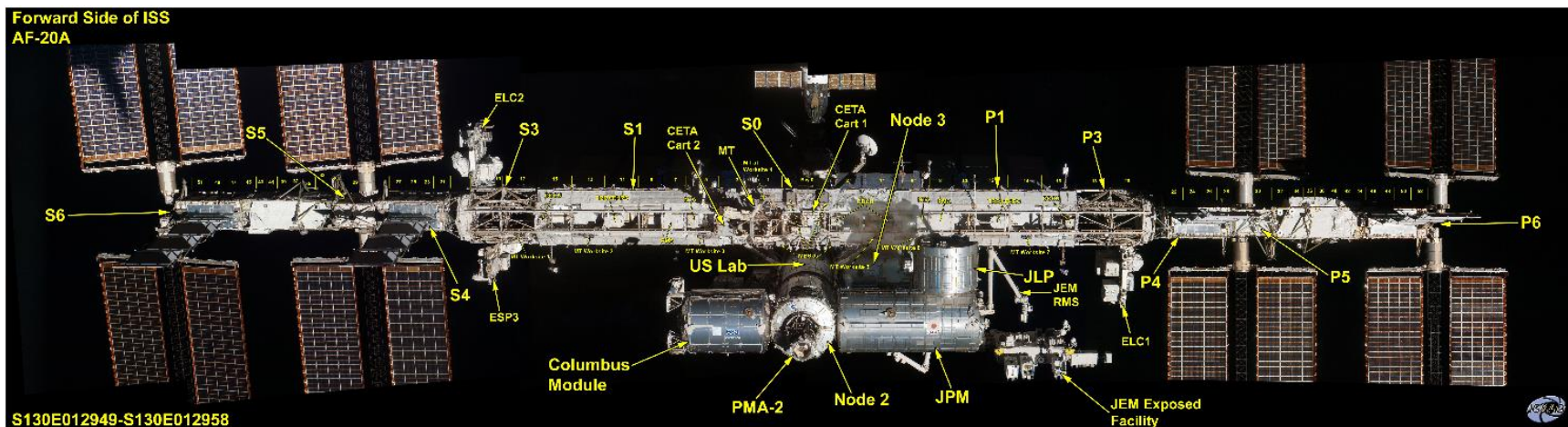
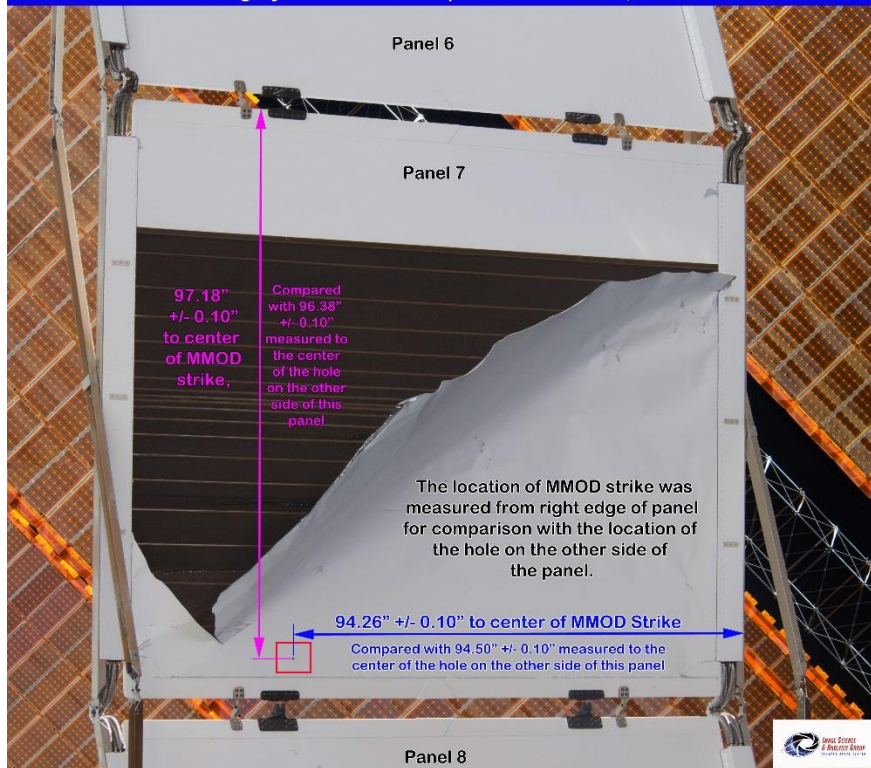


Photo-mosaic constructed from ISS Survey Images



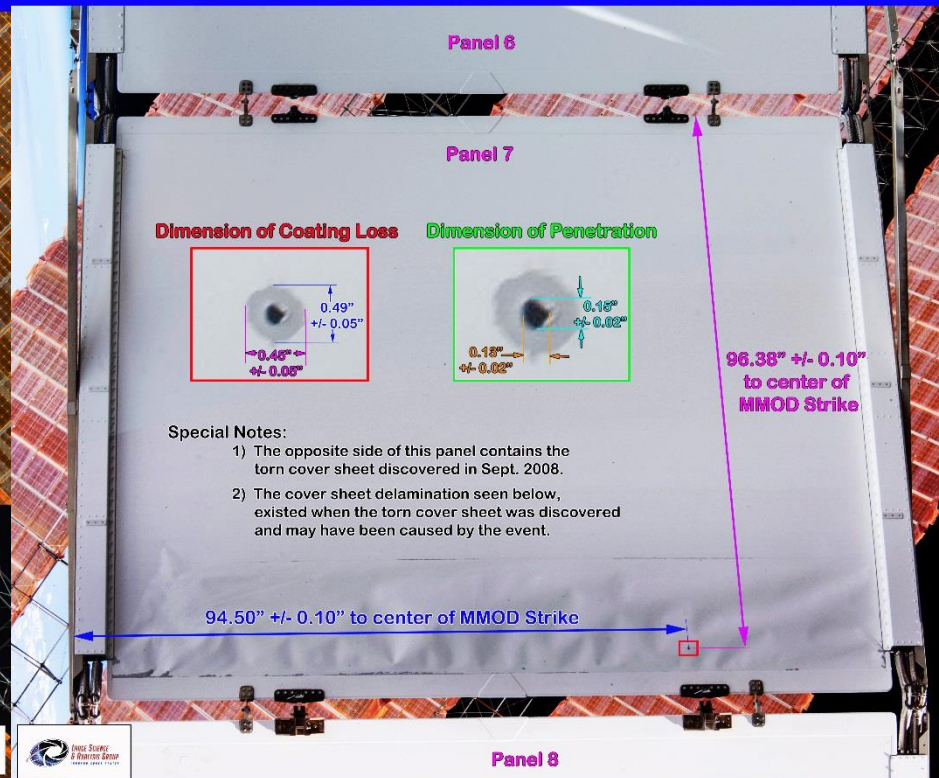
Anomaly Assessment

Comparison of MMOD Strike Location on Front and Back of S-TRRJ HRS Radiator S1-3, Panel #7
Imagery from Periodic Inspection on June 28, 2013



Mosaic of Panel 7 from iss036e012822 and 012823.
Analysis by Projective Plane to Plane Transformation, based on HRS radiator panel dimensions from Loral assembly drawing #83-39411.
Analysis by D. Liddle 7/29/13 Rev. 1.0

MMOD Strike on S-TRRJ HRS Radiator S1-3, Panel #7
Imagery from Periodic Inspection on June 28, 2013



Special Notes:

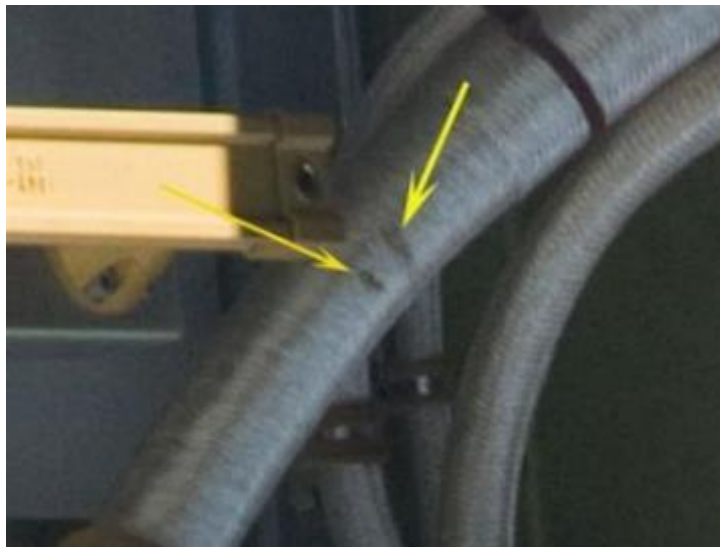
- 1) The opposite side of this panel contains the torn cover sheet discovered in Sept. 2008.
- 2) The cover sheet delamination seen below, existed when the torn cover sheet was discovered and may have been caused by the event.

Mosaic of Panel 7 from images iss36e012933 and 012935, with insets from iss036e012961.
Analysis by Projective Plane to Plane Transformation, based on HRS radiator panel dimensions from Loral assembly drawing #83-39411.
Analysis by D. Liddle 7/26/13 Rev. 1.0

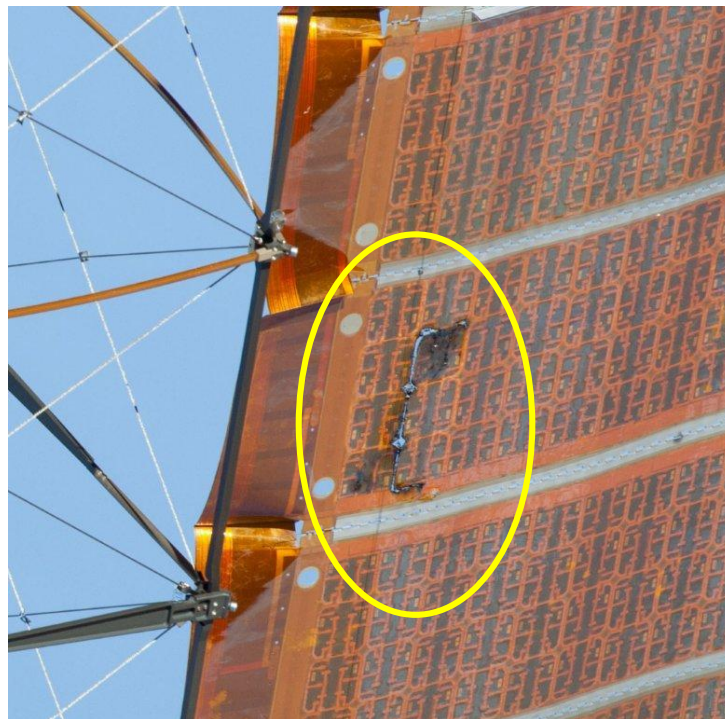
Photogrammetric measurements of thermal radiator panel damage and MMOD strikes



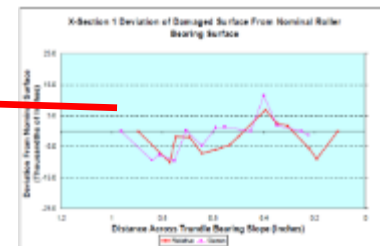
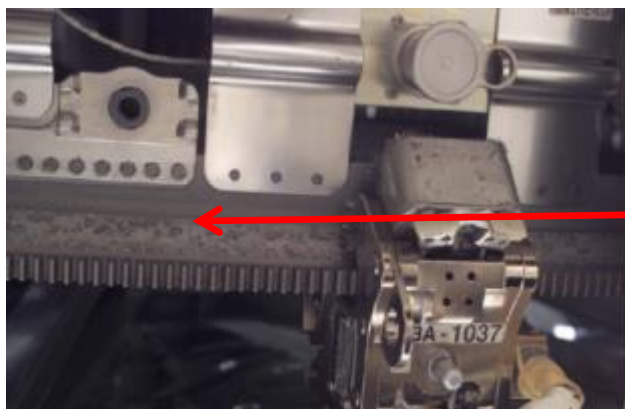
Anomaly Assessment



***Wire Harness Survey for S4
Electrical Anomaly***



***Solar Array Survey for S4
Electrical Anomaly***



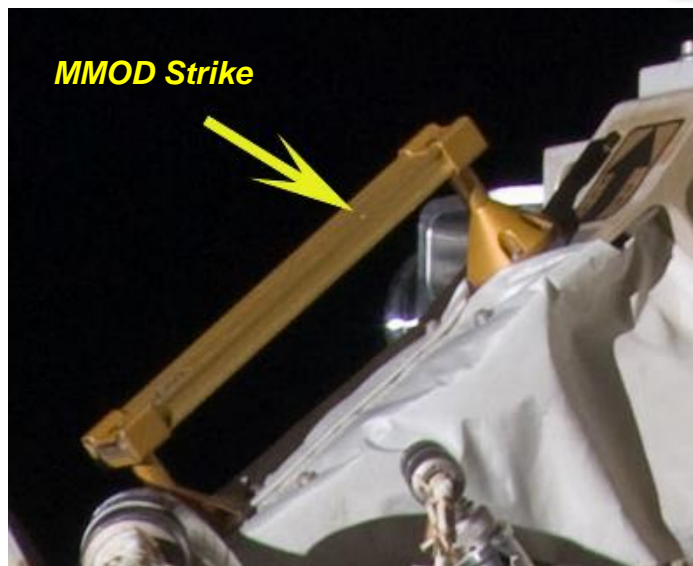
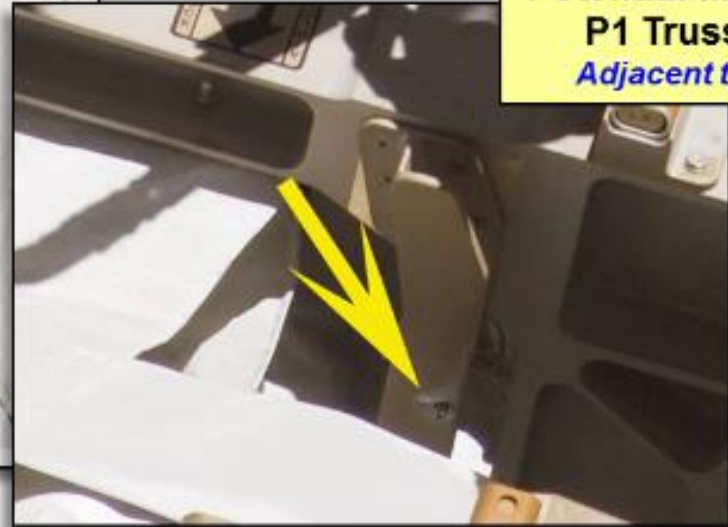
SARJ Roller Bearing Surface Damage



EVA Sharp Edge Inspection

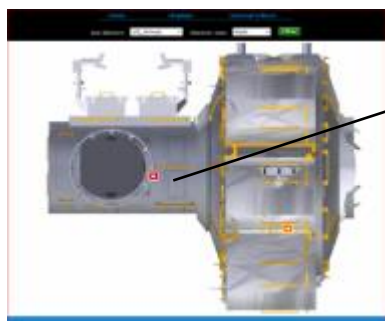
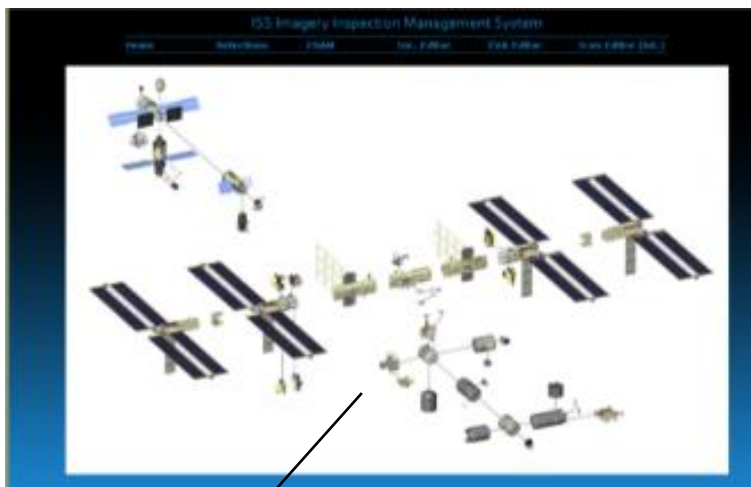


Potential MMOD Strike
P1 Truss Bay 12
Adjacent to Handrail





EVA Sharp Edge Tracking



ISS Airlock Hand Rail Possible MMOD Strike

Preliminary Results of Dimensional Analysis

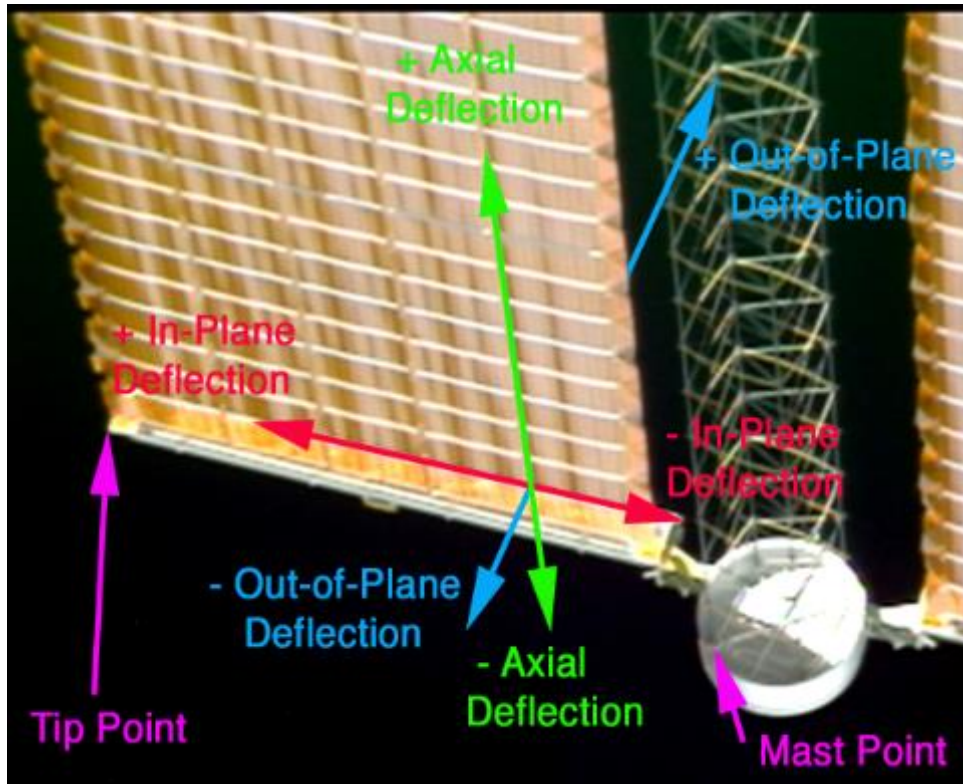
Lip height above Nominal 0.01 +/- 0.005 inches
Crater Depth below Nominal 0.05 +/- 0.03 inches

0.07" Outer Diameter
0.05" Inner Dia.
Diameter varies by +/- 0.01 inches due to irregularities in the shape

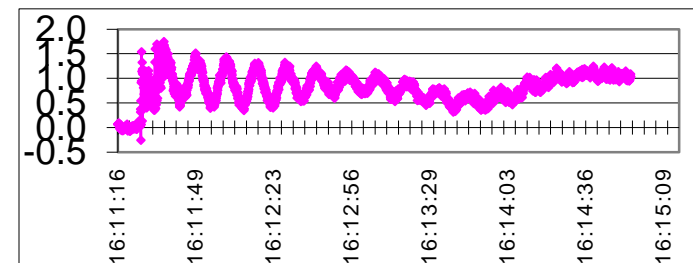
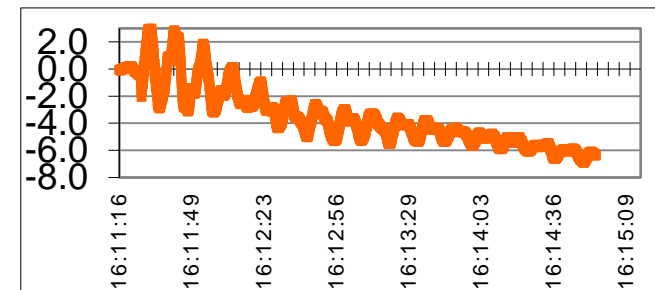
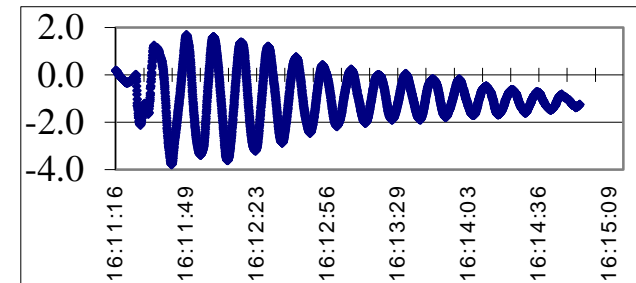
IS&AG Measurements based on convergent and stereo photogrammetric analysis of photography taken on EVA 3 using the hand rail mounting bracket to scale the measurements.
By Don Liddle and Orrin Thomas (JSC-Image Science and Analysis Group)

Element	View	Detection Type	SubSystem Owner		Count: 2	
US_Airlock	nadir	Any	Any	Go Filter		
Issue ID, Owner	Mission, Element, View	Title, ISAG Docs	Type, SharpEdge, XPath	IFI #, PRACA #, Docs	Comments	User, Modified Time
79 ATCS	AF-20A/STS-130 US_Airlock Nadir	Possible MMOD Strike on Center Airlock O2 Tank next to Handrail. doc	MMOD Strike No Yes	TBD TBD	sharp edge should be no because of soft goods	rscharf 5/15/2011 12:00:00 PM
88 TBD	AF-1E/STS-122 US_Airlock Nadir	MMOD strike on US Airlock handrail adjacent to hatch. doc	Sharp Edge Confirmed Yes	TBD TBD	sharp edge is marked with a wiretie, but not repaired or covered.	rscharf 5/15/2011 12:00:00 PM

Verification of Structural Dynamics

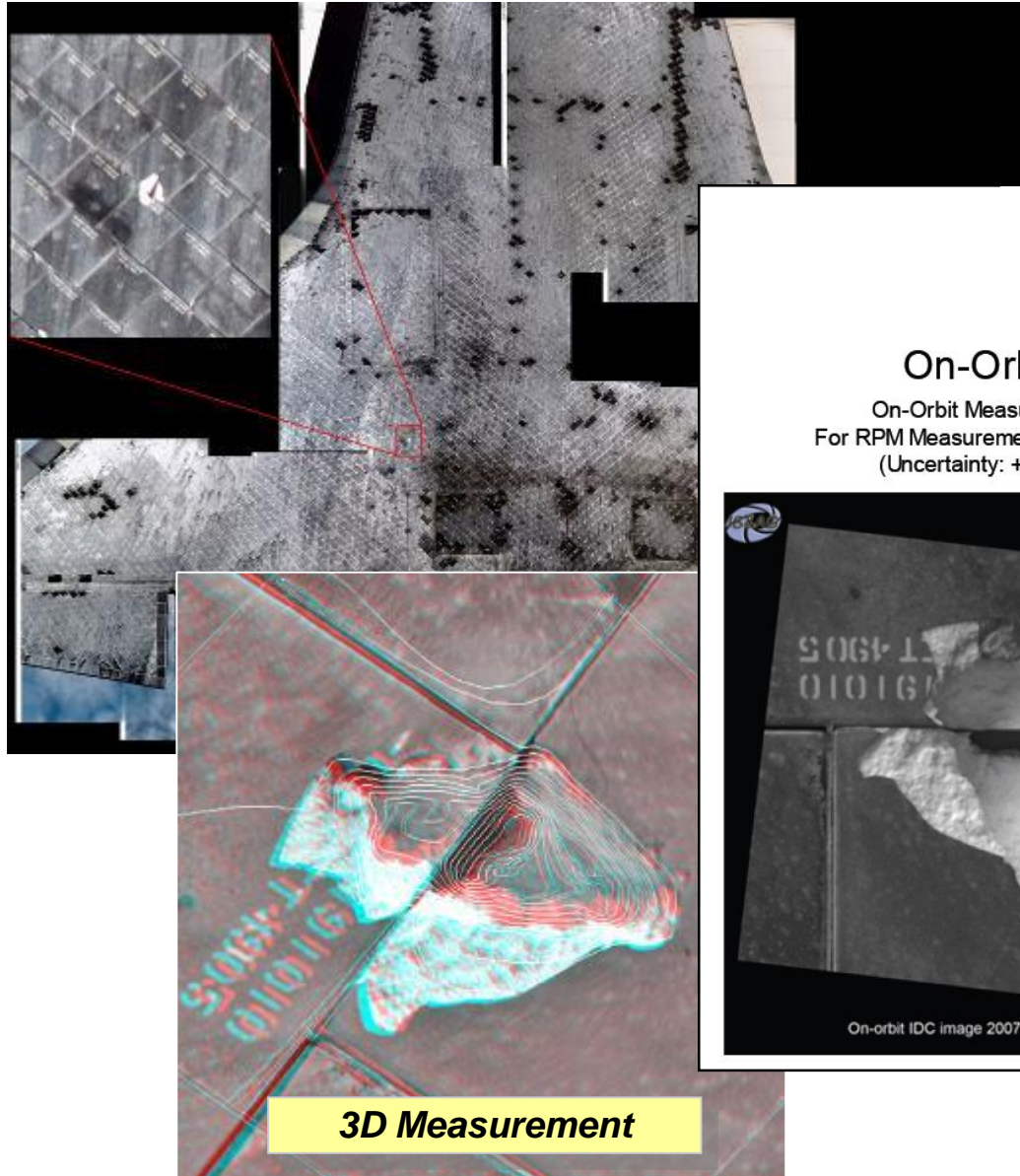


Tracking motion of solar array response to thruster firings





Visiting Vehicle Inspection and Assessment



STS-118 Shuttle TPS Damage

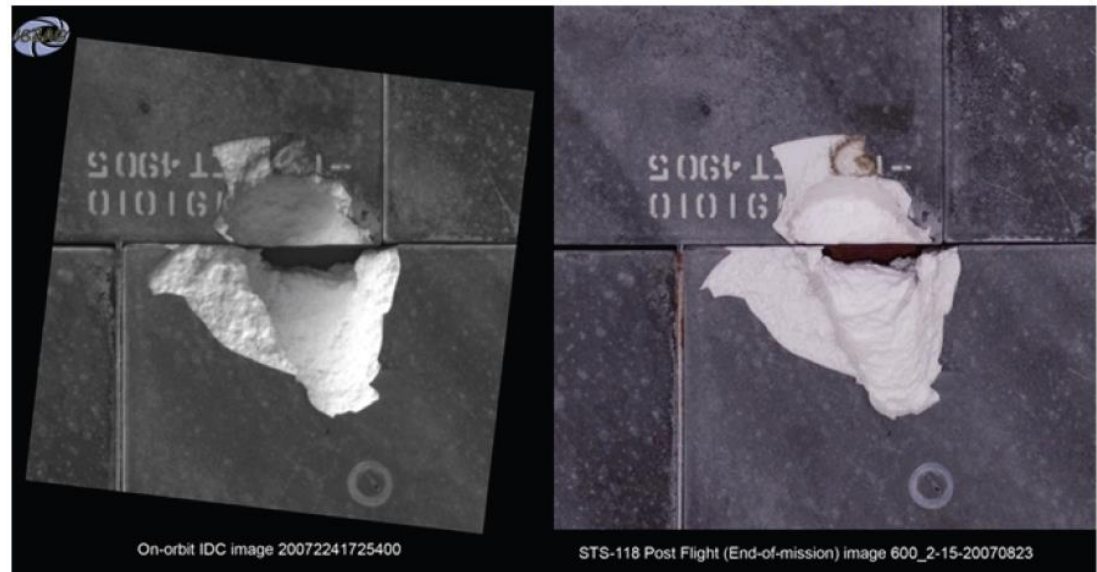
On-Orbit

On-Orbit Measurements:
For RPM Measurements, click [here](#).
(Uncertainty: +/- 0.15")

Post-Flight

Post-Flight Measurement: 3.45" x 2.66" (ISAG)
(Measuring in the same direction as on-orbit,
Length - 3.35", Width - 2.44")

[CLICK HERE FOR ORIGINAL IMAGE](#)

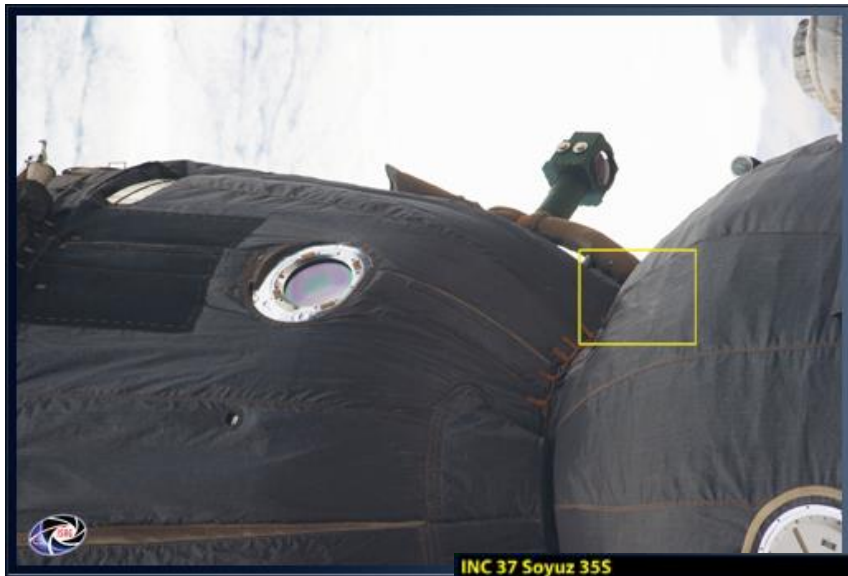


On-orbit IDC image 20072241725400

STS-118 Post Flight (End-of-mission) image 600_2-15-20070823



Visiting Vehicle Inspection and Assessment



INC 37 Soyuz 35S
Cupola W5
D3s w/180mm lens
October 25, 2013

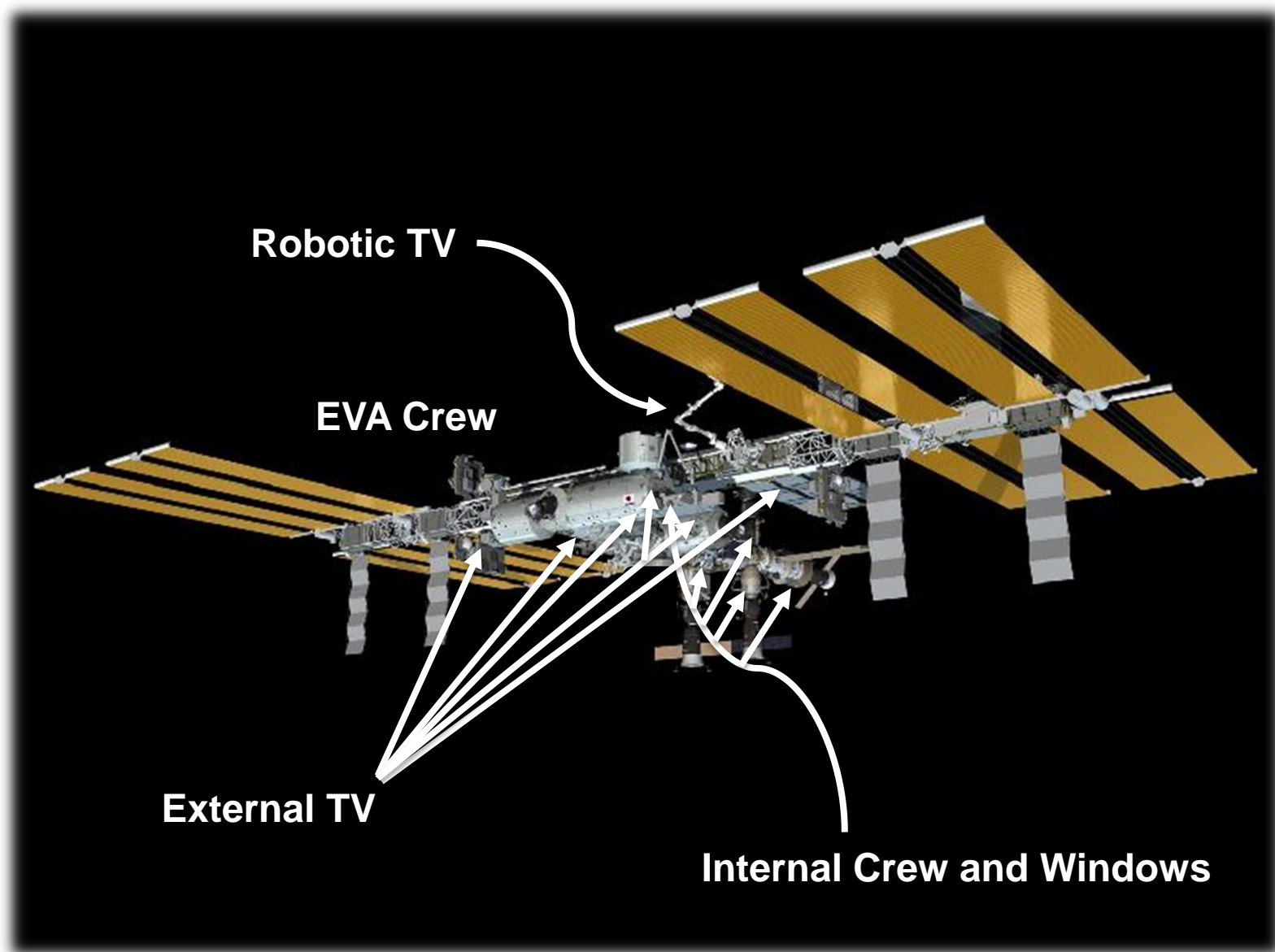




ISS Inspection Assets



ISS Visual Inspection Assets





ISS Camera Assets



➤ EXTERNAL

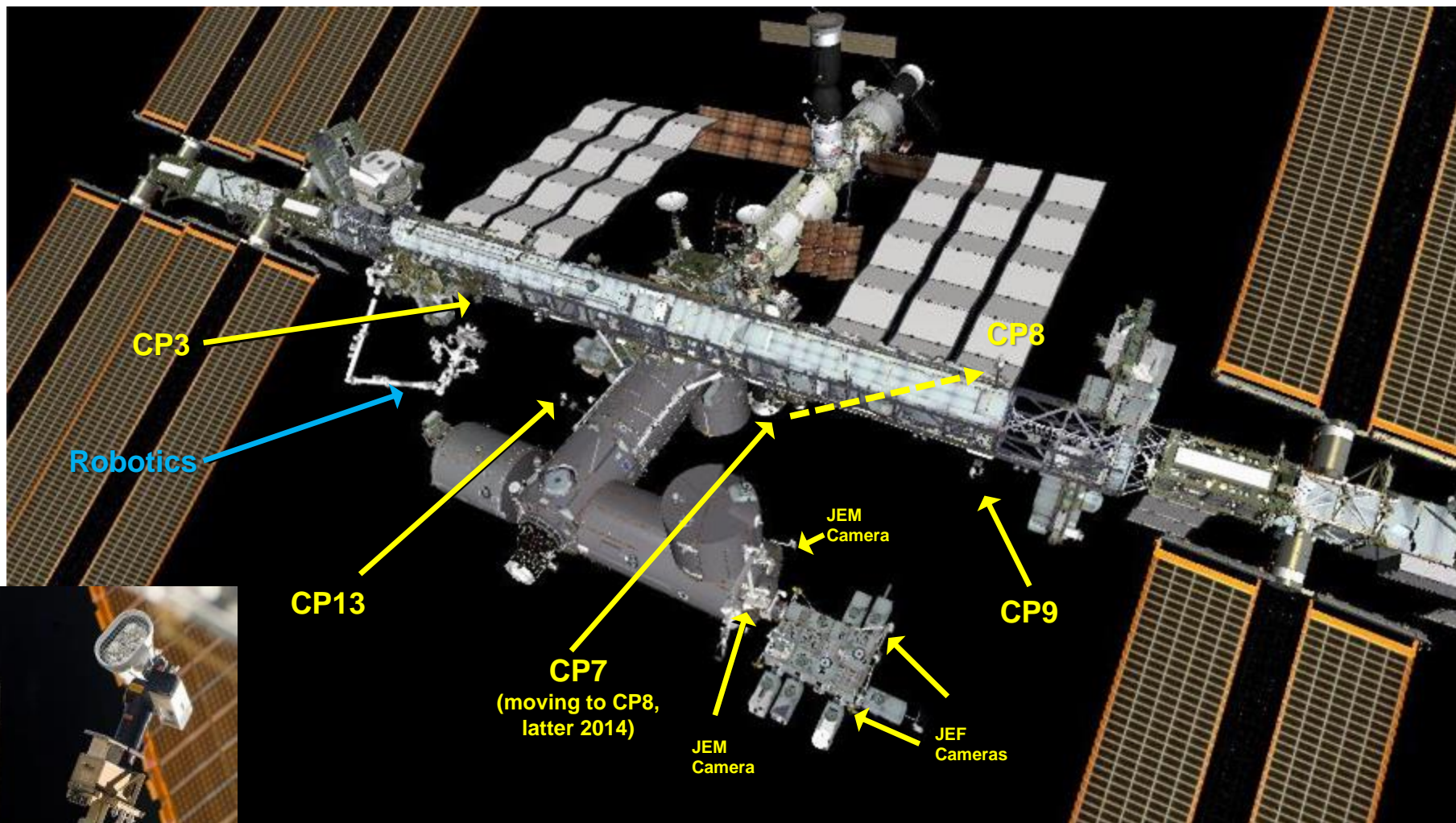
- **Mounted to structure**
 - 4 standard definition TV cameras with lights on pan/tilt units
 - 4 standard definition TV cameras on the JEM bulkhead and JEM Exposed Facility
 - *4 high definition video/still cameras in production*
- **Mounted to robotics**
 - 4 standard definition TV cameras (2 with lights and pan/tilt) on SSRMS
 - 4 standard definition TV cameras (2 with lights and pan/tilt) on SPDM
 - 1 standard definition TV cameras with light and pan/tilt on MBS
 - 3 standard definition TV cameras (2 with pan/tilt) on JAXA JEM EF arm
- **Crew equipment**
 - 3 standard definition TV cameras with lights (wireless) on helmet
 - Nikon digital SLR with selection of lenses and a flash unit
 - Infrared Camera

➤ INTERNAL

- **Mounted to structure**
 - Wall mounted video camcorders for MCC situational awareness & public affairs
 - Centerline Berthing camera system
- **Crew handheld**
 - Selection of Nikon D2XS, D3S and D4 digital SLRs, lenses, and flashes
 - 1 Nikon D3S modified for near-IR
 - Selection of 2D and one 3D Video Camcorders
 - Minicam with fiberscope



External ISS Television Cameras



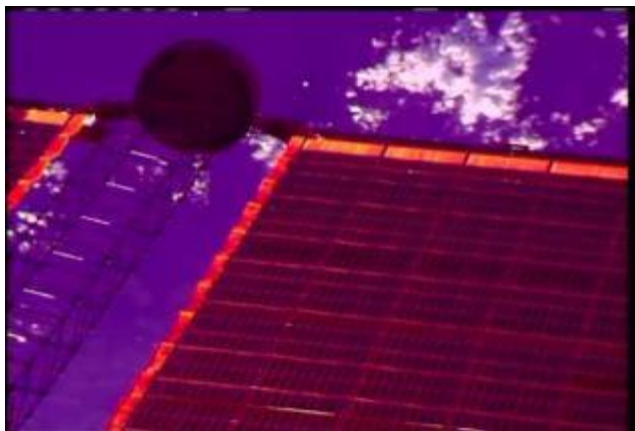
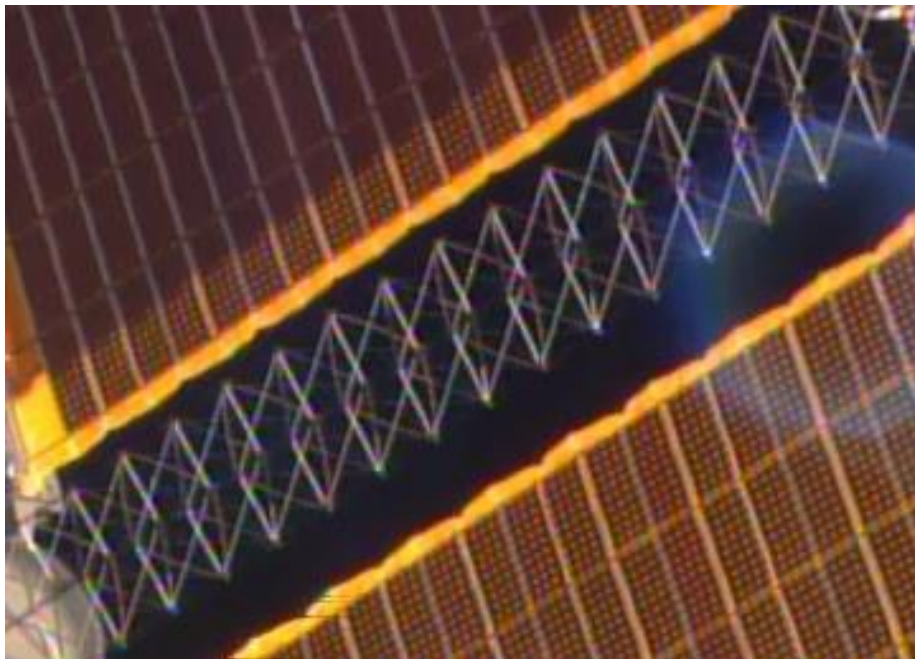
ETVCG – External TV Camera Group (4)
NTSC, 525 horizontal lines (USOS Standard)
CCD sensor
FOV: Max: 77x61 Min: 10x8°
Zoom ratio ~8:1

**JEM EF – JAXA Experiment Module
Exposed Facility**
NTSC, CCD

Note: High Definition Video/Still DSLR/zoom lens to be attached to each ETVCG beginning 2015



External ISS Television Cameras (Structurally Mounted)





ETVCG Inspection Challenges



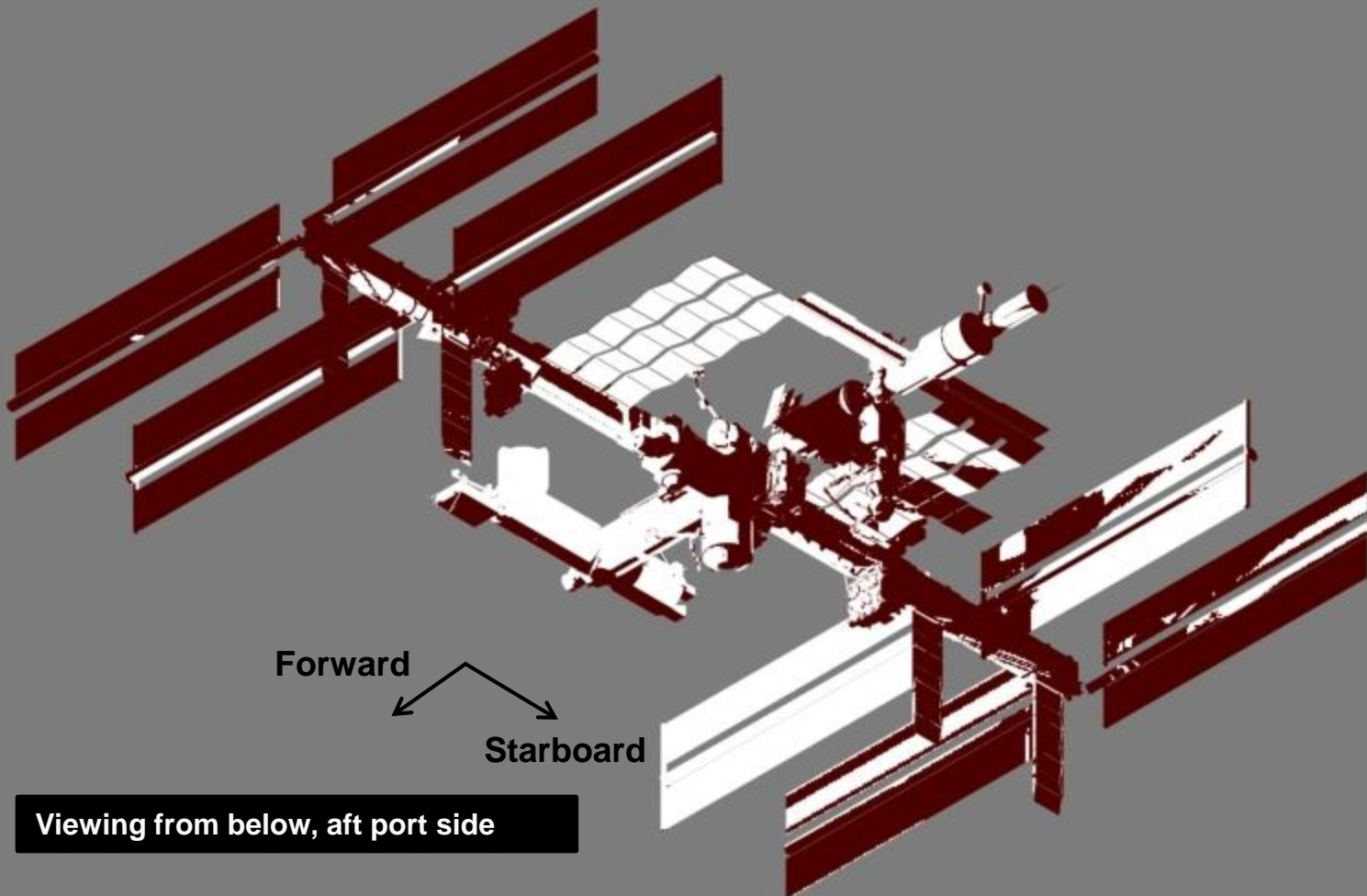
- **Limited camera installation locations, numerous blindspots**
- Resolution limitations – generally not adequate for detailed inspections
 - Standard definition TV
 - Compression of the video for downlink
 - Distance and high incidence viewing
 - *External high definition cameras planned for 2015 should dramatically improve capability*
- Hardware failure and degradation reduces capability
 - Three of four ETVCG cameras currently have issues (pink tint, intermittent stuck zoom and intermittent stuck iris)
 - Limited spares and opportunities to replace
- JEM cameras are not readily available
 - Camera operational time is minimized to conserve life
 - Pan and tilt via uplinked command script



External TV Camera Coverage (ETVCGs (4) + JEM (4))



Brown shading shows current ETVCG and JEM cameras
“blind spots”



Forward

Starboard

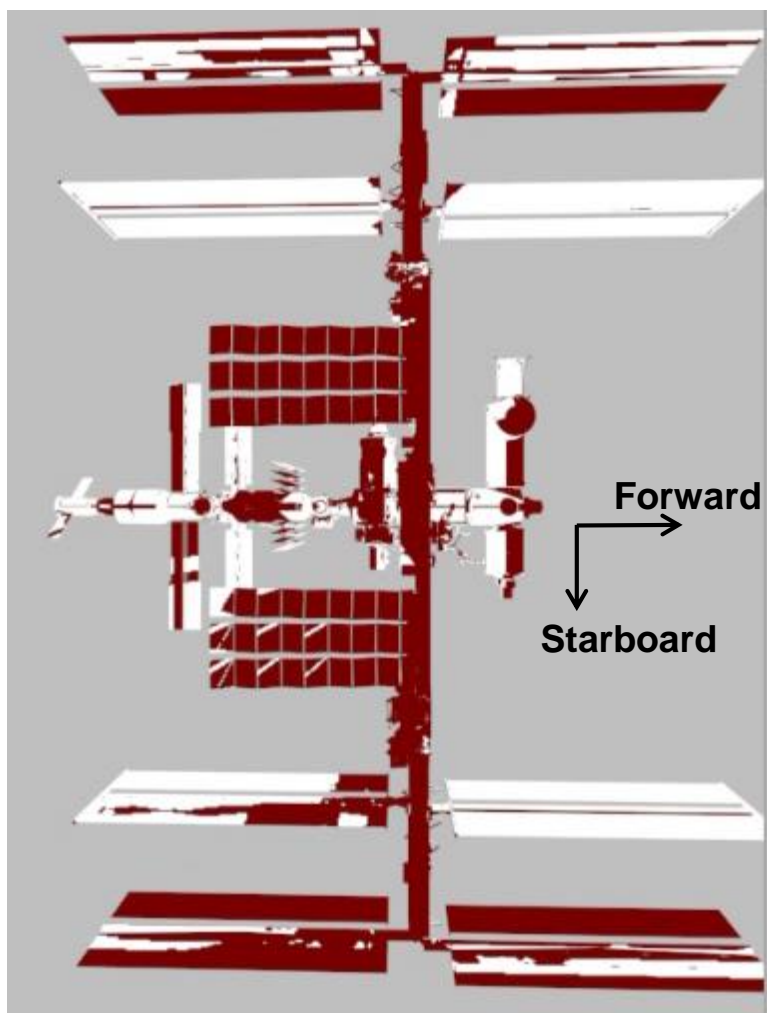
Viewing from below, aft port side



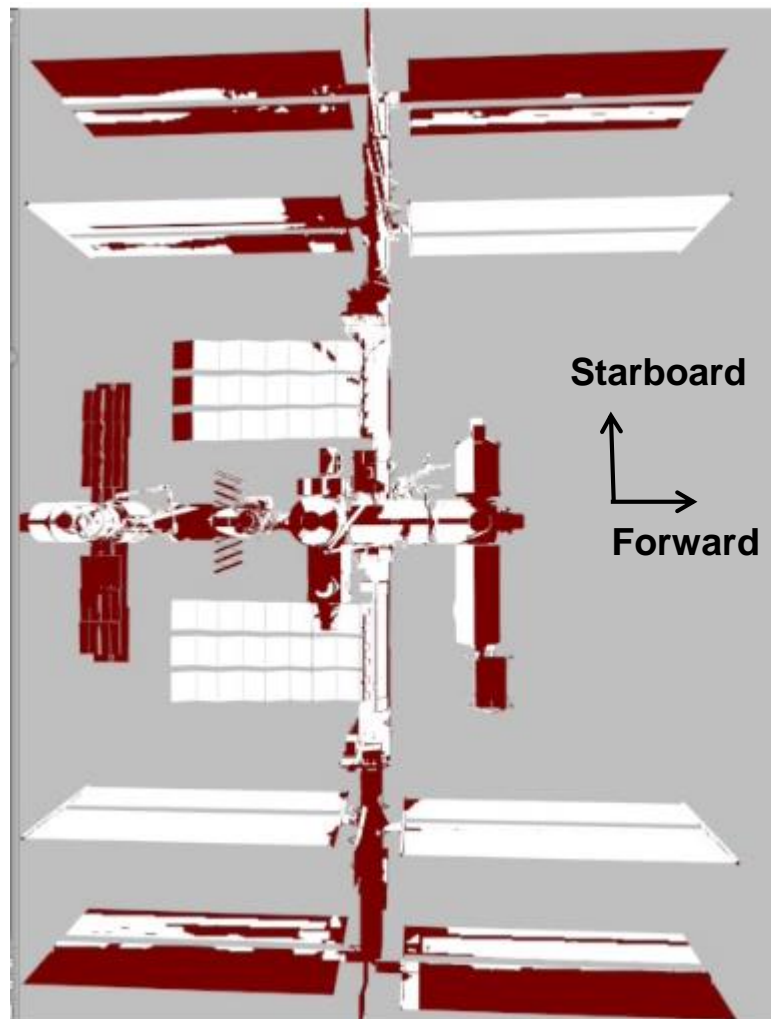
External TV Camera Coverage (ETVCGs (4) + JEM (4))



Brown shading shows current ETVCG and JEM cameras “blind spots”



Viewing from above



Viewing from below



ETVCG Inspection Challenges



- Limited camera installation locations, numerous blindspots
- **Resolution limitations – generally not adequate for detailed inspections**
 - **Standard definition TV**
 - **Compression of the video for downlink**
 - **Distance and high incidence viewing**
 - ***External high definition cameras planned for 2015 should dramatically improve capability***
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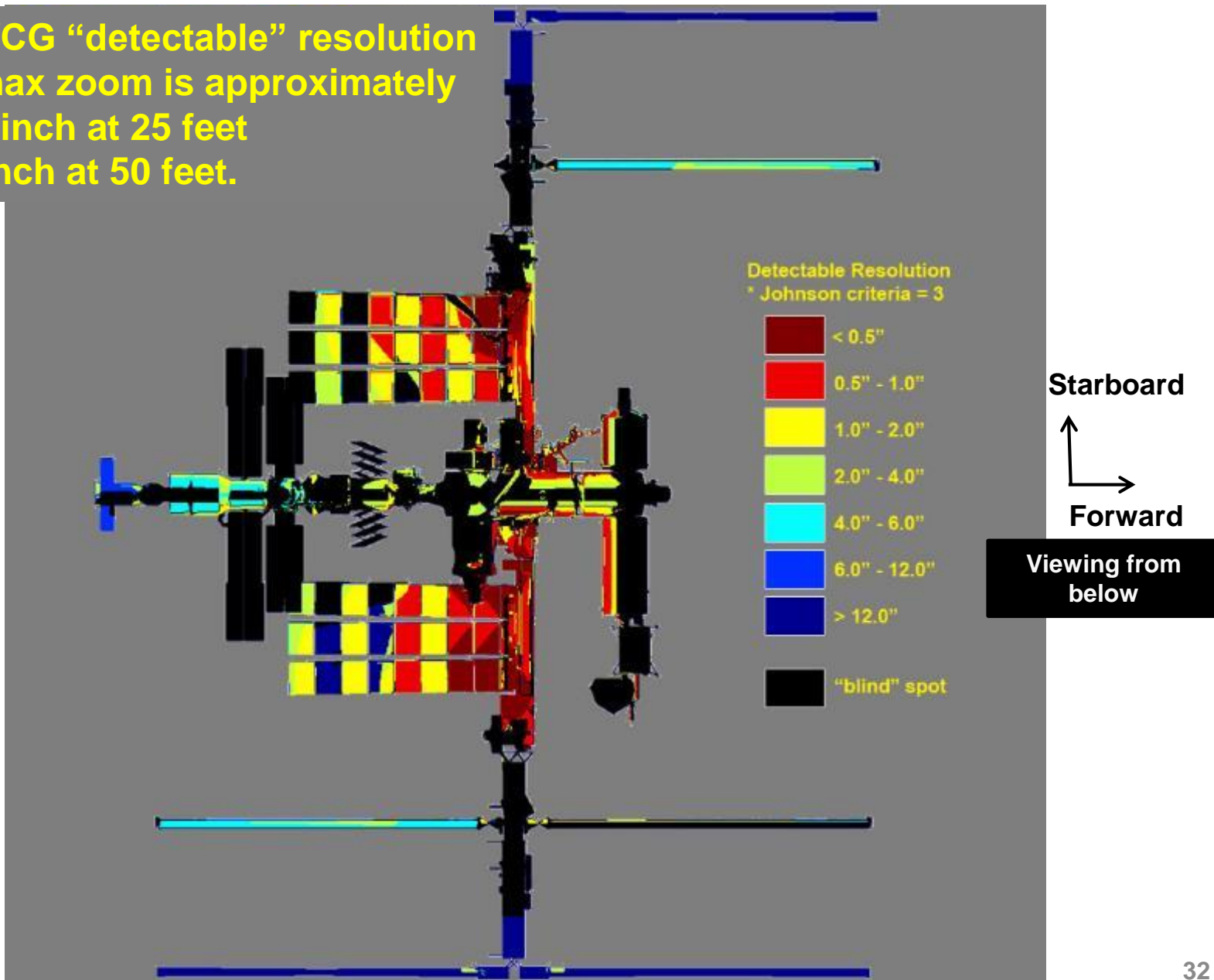


External TV Cameras Resolution Analysis

All ETVCGs Combined (4)



ETVCG “detectable” resolution
at max zoom is approximately
.25 inch at 25 feet
.5 inch at 50 feet.





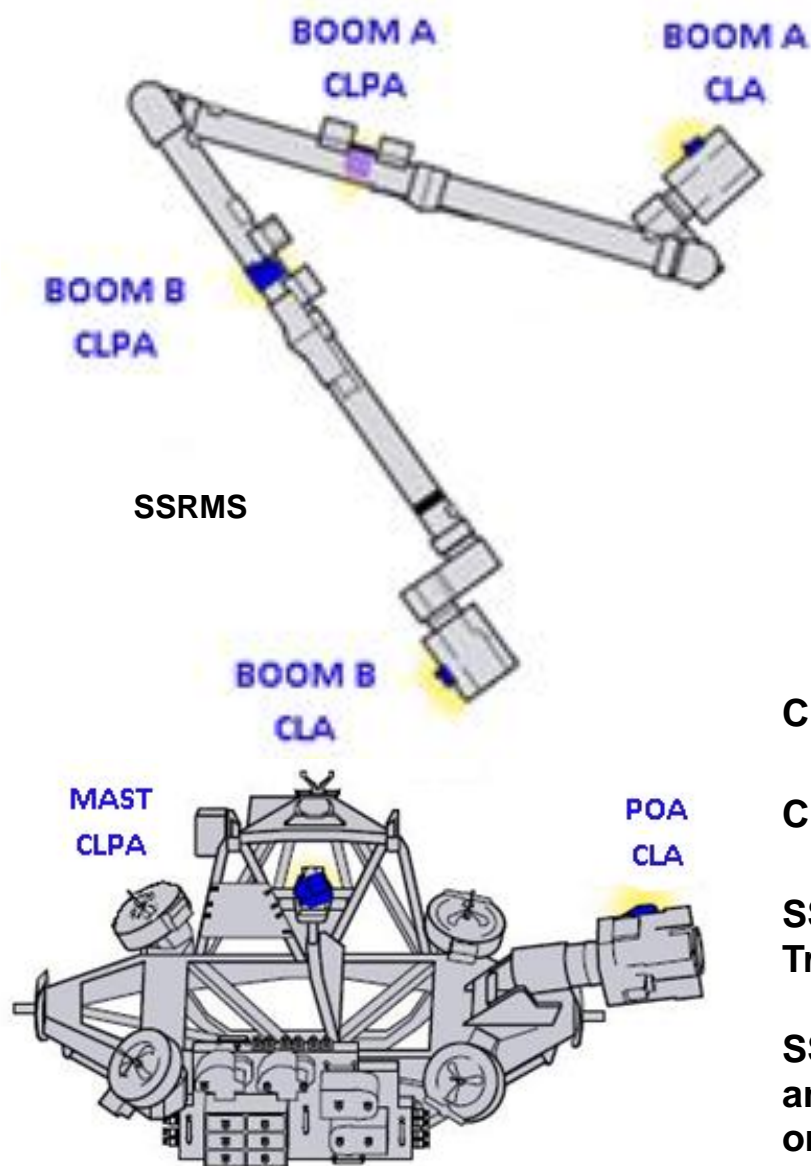
ETVCG Inspection Challenges



- Limited camera installation locations, numerous blindspots
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- **JEM cameras are not readily available**
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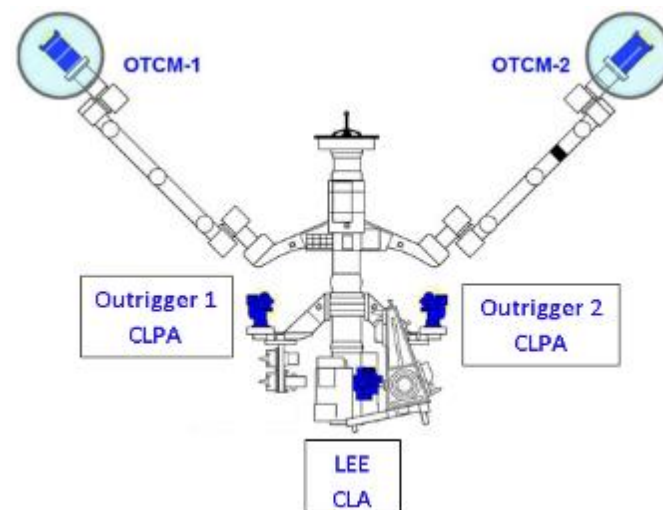


External Television Cameras (Mobile Servicing System)



SSRMS

Mobile Base System



Special Purpose Dexterous Manipulator
(SPDM)/DEXTRE

CLA - Camera and Light Assembly (CLA)

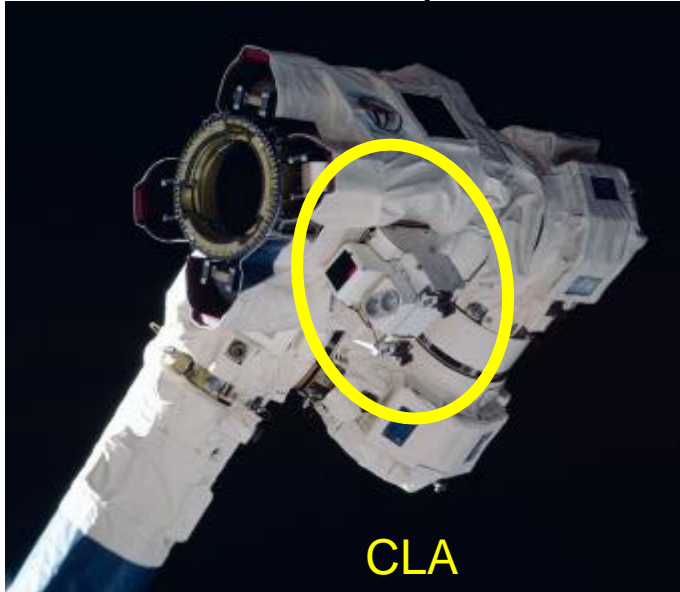
CLPA - Camera / Light / Pan-Tilt Unit Assembly

SSRMS moves along truss when attached to Mobile Transport/Mobile Base System (MT/MBS).

SSRMS is operational along truss at MT Worksites and Power and Data Grapple Fixtures (PDGF) located on USOS modules and Russian FGB.

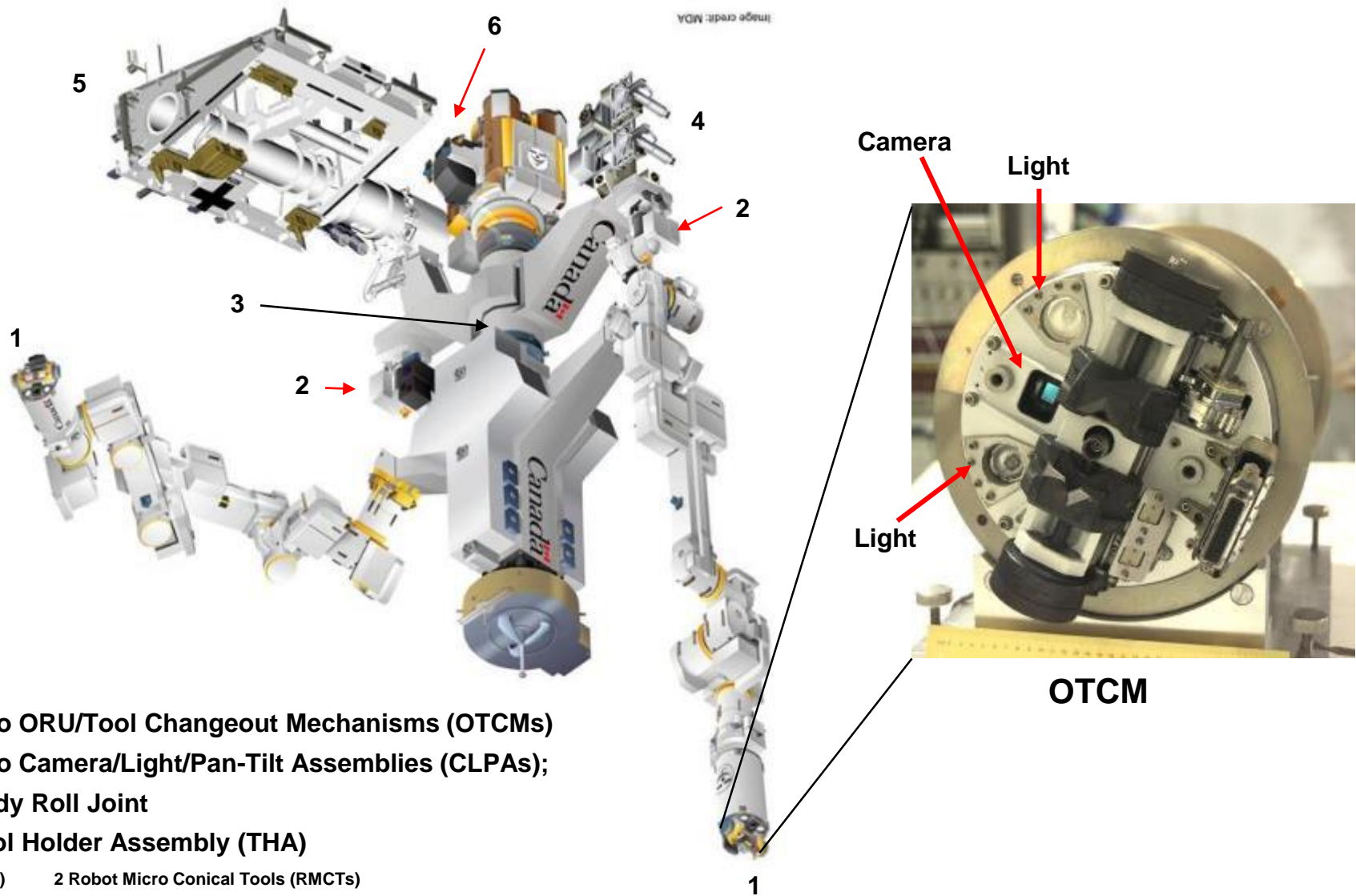


External Television Cameras (Mobile Servicing System)



- Both CLA and CLPA utilize the same CCD camera and lights
- FOV Max ~ 52° x 40°, ~9mm focal length,
Min ~ 6°x4° , ~84mm focal length
- Zoom ratio ~9:1
- The minimum viewing distance is 14 in.
- MSS camera “detectable” resolution at max zoom is approximately
 - ~.2 inch at 25 feet
 - ~.4 inch at 50 feet.
- Standard ETVCG and MSS frame rate: 30 fps

SPDM (DEXTRE) Overview

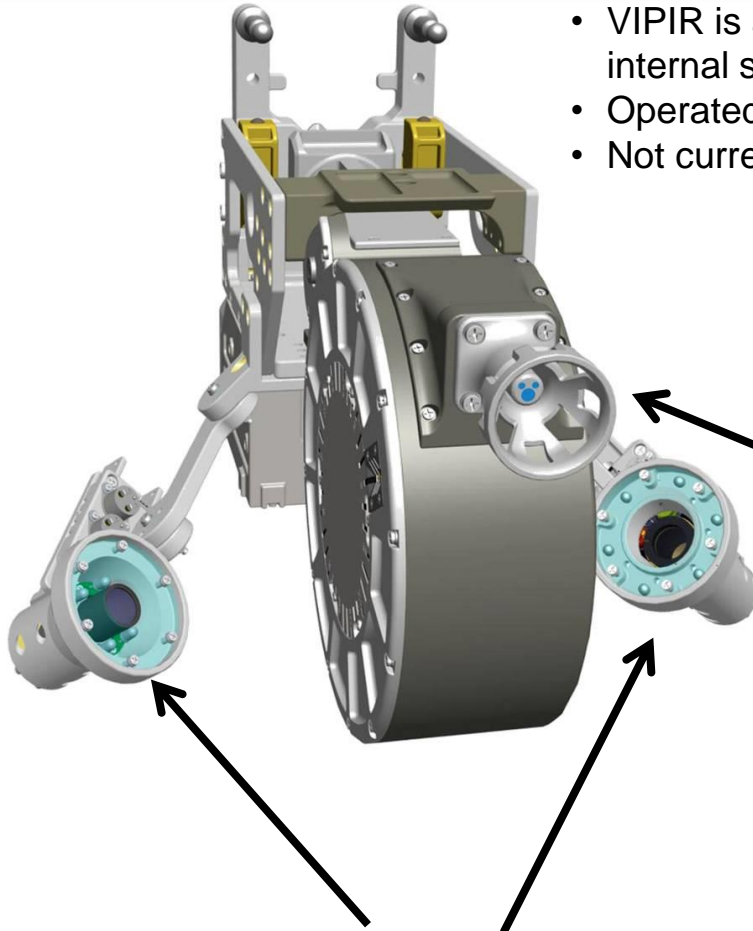


1. Two ORU/Tool Changeout Mechanisms (OTCMs)
2. Two Camera/Light/Pan-Tilt Assemblies (CLPAs);
3. Body Roll Joint
4. Tool Holder Assembly (THA)
 - a) 2 Robot Micro Conical Tools (RMCTs)
 - b) Socket Extension Tool (SET)
 - c) Robotic Offset Tool (ROST)
5. Enhanced ORU Temporary Platform (EOTP)
6. SPDM Latching End Effector (LEE) with Camera/Light Assembly (CLA)



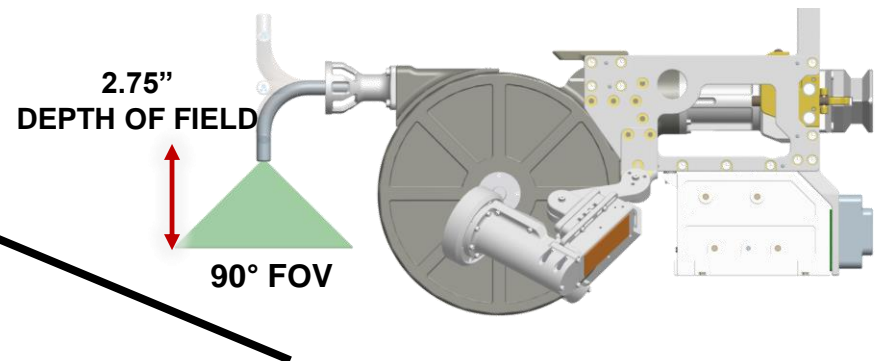
Visual Inspection Poseable Invertebrate Robot (VIPIR)

- Manifested on ATV-5 for the Robotic Refueling Mission demonstration.
- VIPIR is a "boroscope" inspection tool that provides a set of eyes for internal satellite repair jobs.
- Operated through SPDM (DEXTRE)
- Not currently planned for permanent stowage on ISS.



Primary and Secondary Tool Vision Cameras

- NTSC, Color, VGA (640 x 480)
- Fixed 6mm and 8-24mm zoom focal lengths
- Full view of Reel Position visual indicators



Video Borescope Assembly (VBA)

- Miniaturized Close-range Inspection Camera and light
- NTSC Color Video (224 x 224 pixels)
- 0.93" diameter tube
- 36" maximum deployment - straight line
- Tip manipulation only
- Tip Control, limited monitoring from ground
- Limited to one camera view at a time through SPDM



Robotics Inspection Challenges



- **Robotic Operations are generally complex and require extensive planning.**
- **After planning joint angles/operations and then moving the manipulator to the inspection location, the viewing and resolution still might not be sufficient.**
- **Future inspection systems could plan to launch internally, but then go external, however the only robotic option is to go through the JEM Airlock**
 - **JEM Airlock usage is limited to a certain number of cycles per year**
 - **JEM Airlock usage requires use of limited IVA crew time**



EVA Crew Cameras



Wireless Video System

- Three SONY XC-999 cameras
- HFOV = 85°, 56° and 30°
- Fixed depth of focus 12 inches to 25 feet.
- Detectable resolution .25-.5 inch at 10 feet.



Digital SLR

- Nikon D2XS and soon, D4
- Lens focal lengths 10.5-180mm





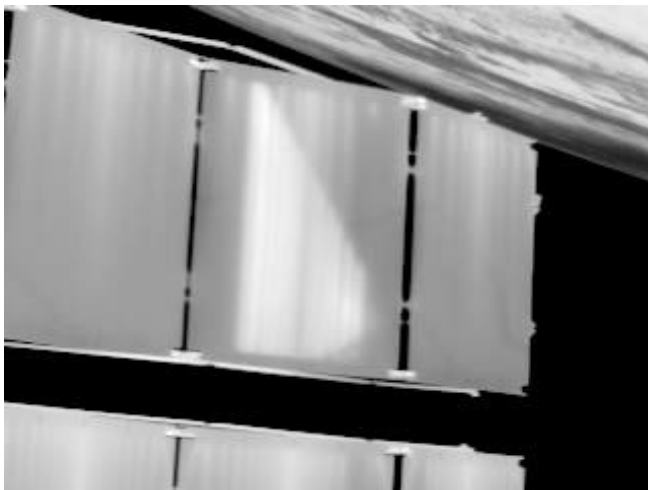
External/Internal IR Camera



Repackaged FLIR Systems ThermaCAM S60 Infrared Camera

Used for inspections of:

- Electrical components
- Radiators
- Solar Arrays
- Heaters



**Infrared View of Damaged Thermal Radiator
(back-side surface)**





Internal Crew Cameras



- Handheld still cameras provide the highest imaging resolution of any of the existing ISS imaging assets.

- Nikon D2XS, D3S and D4 Digital Still Cameras
- Lenses ranging from 8mm to 1200mm
- One Nikon D3s modified for near IR photography/video

High Definition Video



Canon XF305 – mounted and handheld.



Panasonic 3DA1 – 3D video capability



Internal Crew Cameras



Drift Ghost S Action Camera used for:

- Obtaining HD video in tight spaces
- Over the shoulder views for ground situational awareness.



Sony XC-999 Mini-cam

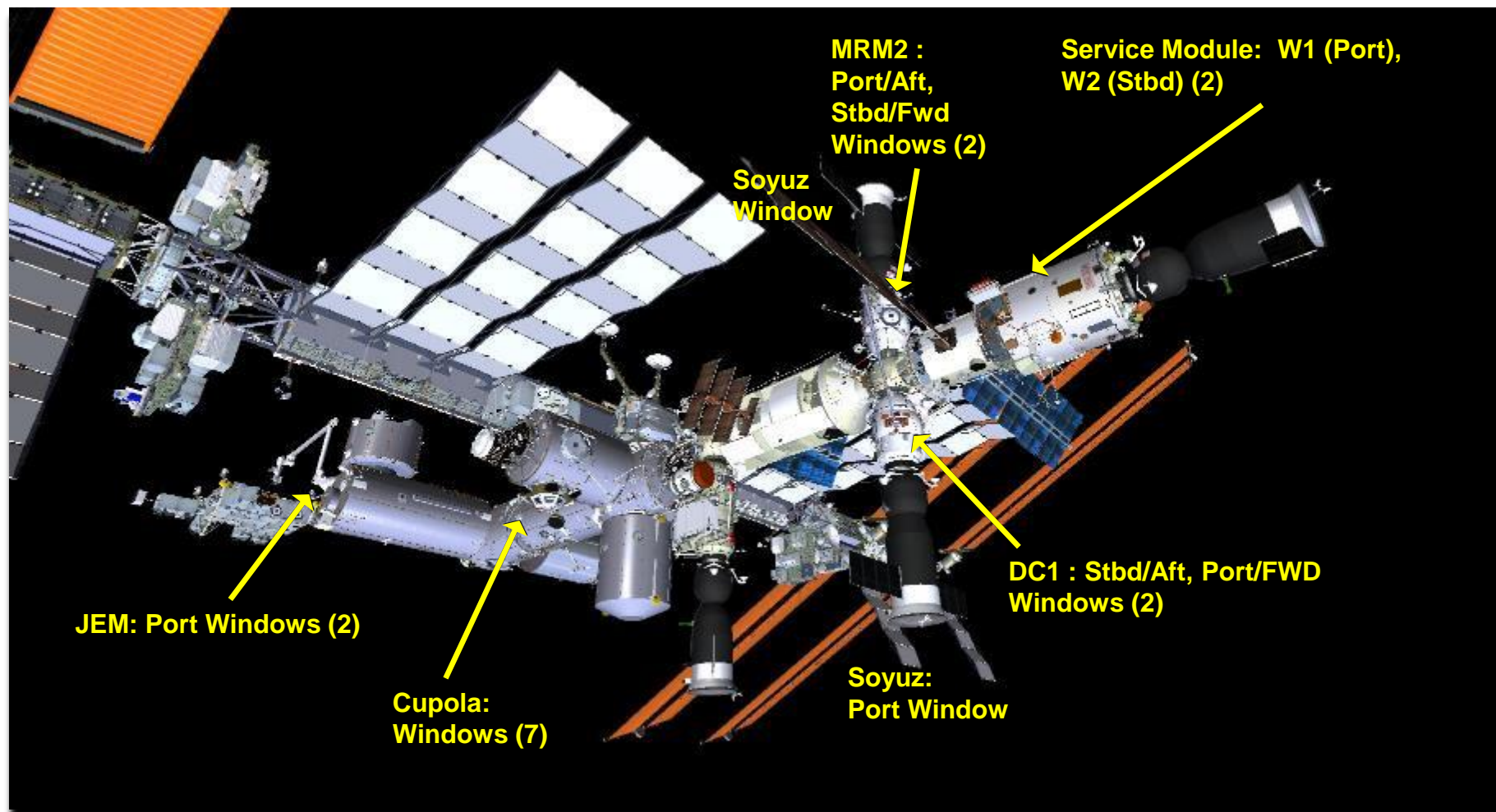
Video camera with fiberscope

Binoculars

- 8x32
- 20x60



Windows for External Surface Inspection



Russian segment and Cupola windows provide coverage of truss aft surfaces and JEM windows provide coverage of port, forward truss surfaces not visible in ETVCG blind spots.

Not all windows are referenced



Example Views from ISS Windows

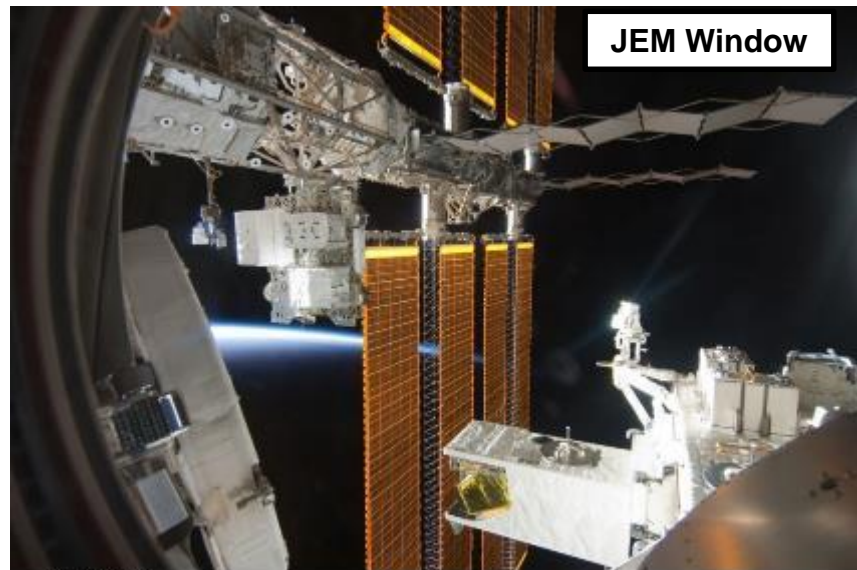


MRM2 Starboard/Forward Window



S129E007742

JEM Window



S133E008894

MRM2 Port/Aft Window



Cupola Windows





Crew External Inspection Challenges



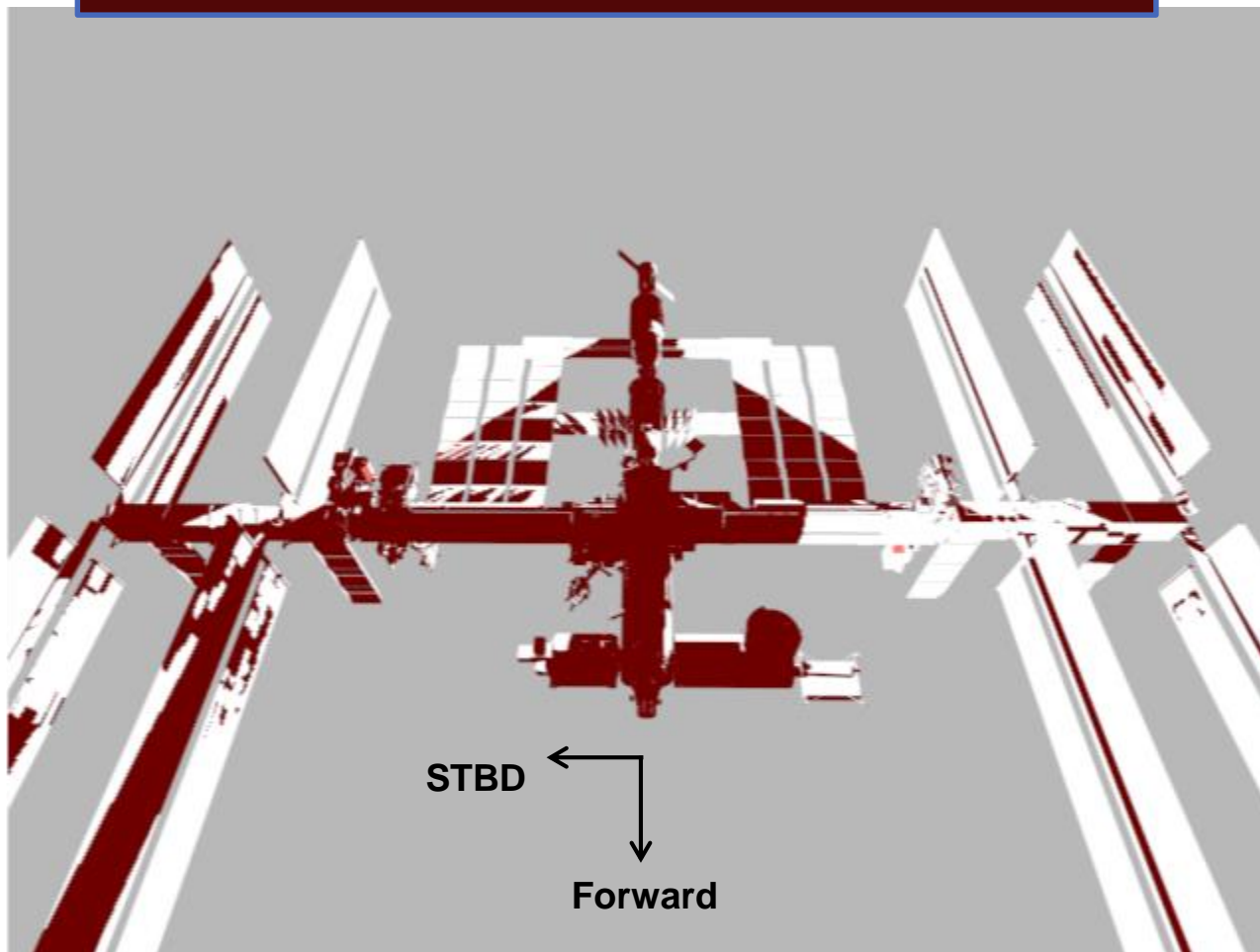
- **Limited windows, numerous blindspots**
 - **Distance and high incidence viewing**
- Protective plastic scratch panes installed over Cupola and JEM windows reduce image resolution but need justification for removal and the removal and reinstallation process is time consuming (Cupola ~4 hours).
- Limited crew time for imagery acquisition support (IVA and EVA)
- EVA – no time for dedicated surveys
 - Lens usually selected for large field of view



ISS Window View Coverage



Brown shading shows window “blind spots”



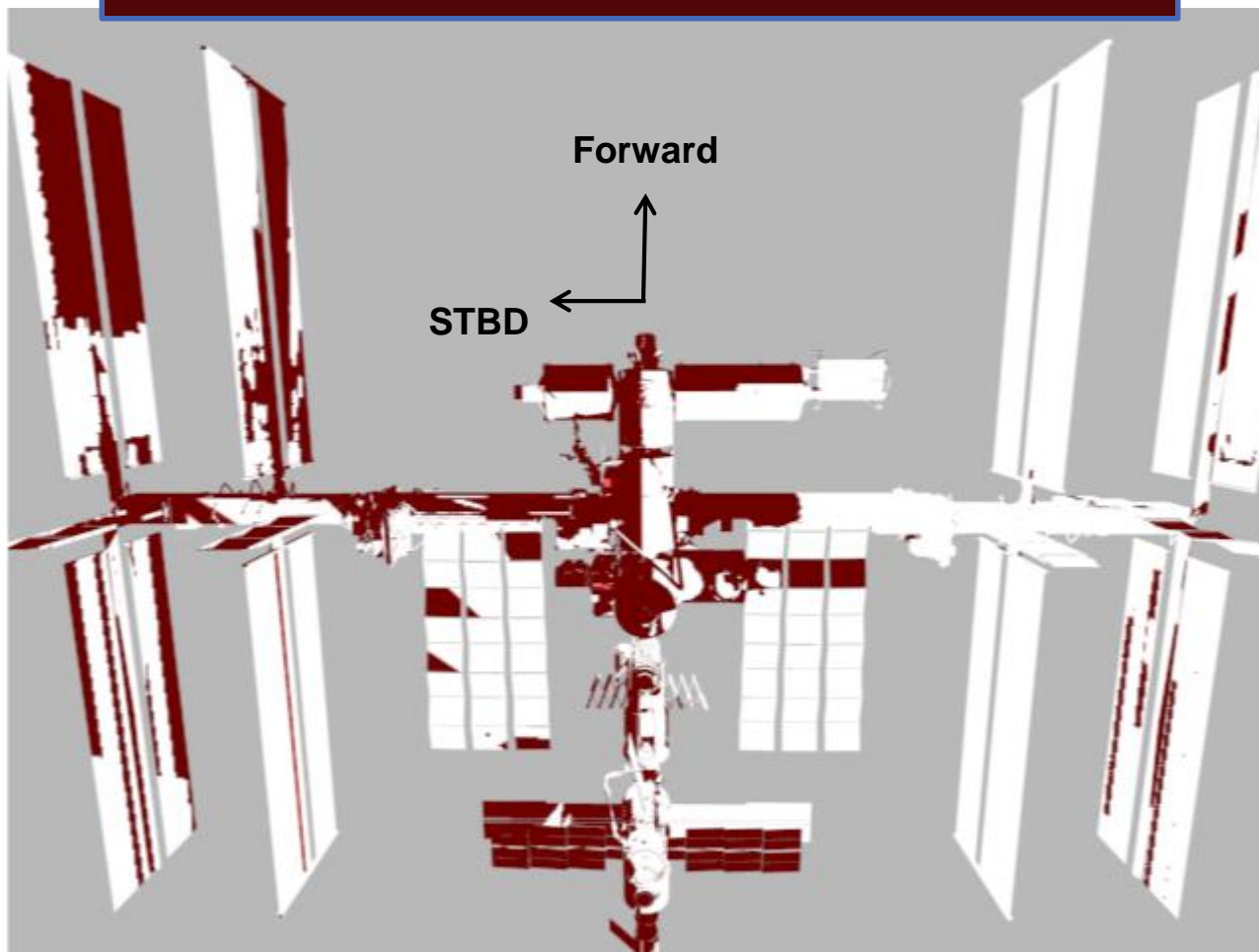
Viewing from above



ISS Window View Coverage



Brown shading shows window “blind spots”



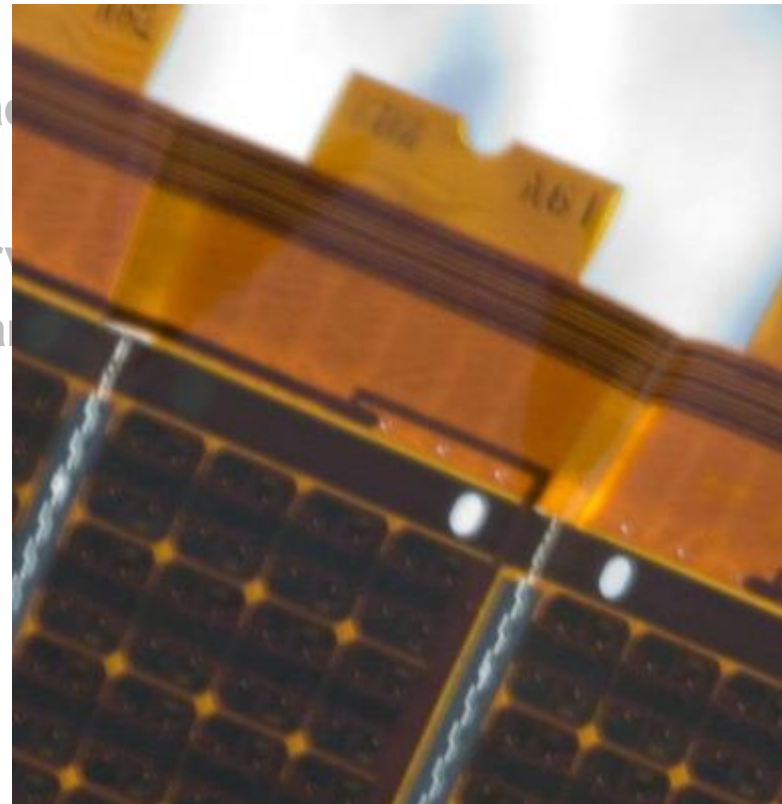
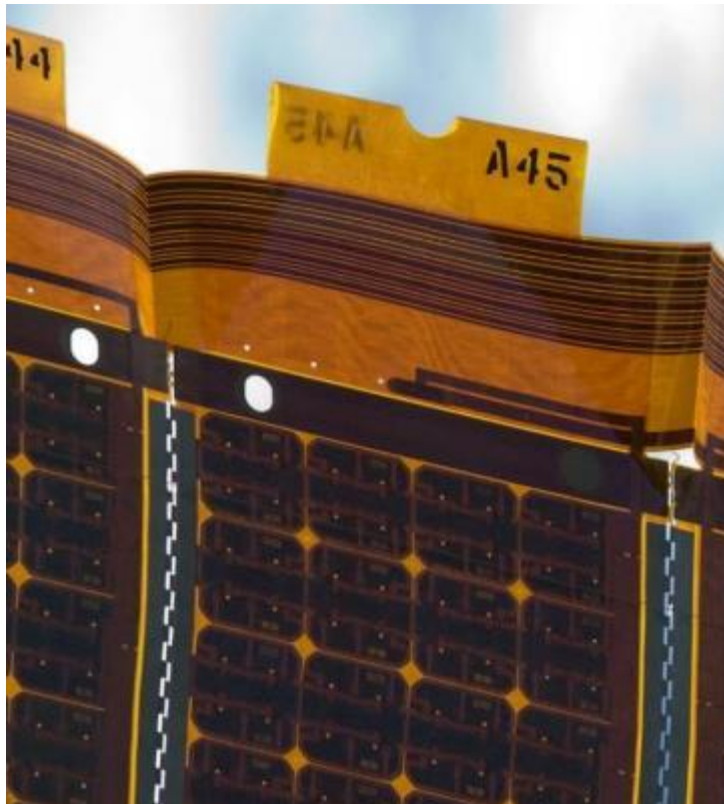
Viewing from below



Crew External Inspection Challenges



- Limited windows, numerous blindspots
 - Distance and high incidence viewing
- **Protective plastic scratch panes installed over Cupola and JEM windows reduce image resolution but need justification for removal and the removal and reinstallation process is time consuming (Cupola 1-4 hours).**





Crew External Inspection Challenges



- Limited windows, numerous blindspots
 - Distance and high incidence viewing
- Protective plastic scratch panes installed over Cupola and JEM windows reduce image resolution but need justification for removal and the removal and reinstallation process is time consuming (Cupola ~4 hours).
- **Limited crew time for imagery acquisition support (IVA and EVA)**
- **EVA – no time for dedicated surveys**
 - **Lens usually selected for large field of view**



Other ISS Inspection Technologies



- Handheld Ultrasonic leak detector
- Ammonia Mass spectrometer



- Challenges for Internal Inspection:
 - Stowage can be in the way
 - Crew time to rotate racks can be hours
 - Some issues (e.g. module leak) could reduce risk(time) with better IVA tools:
 - Improve Ultrasonic Leak Detector adapters
 - Full-length Controllable Stereo View Endoscopes
 - Access NDE inspection after leak plug has been installed



Inspection Challenges Summary



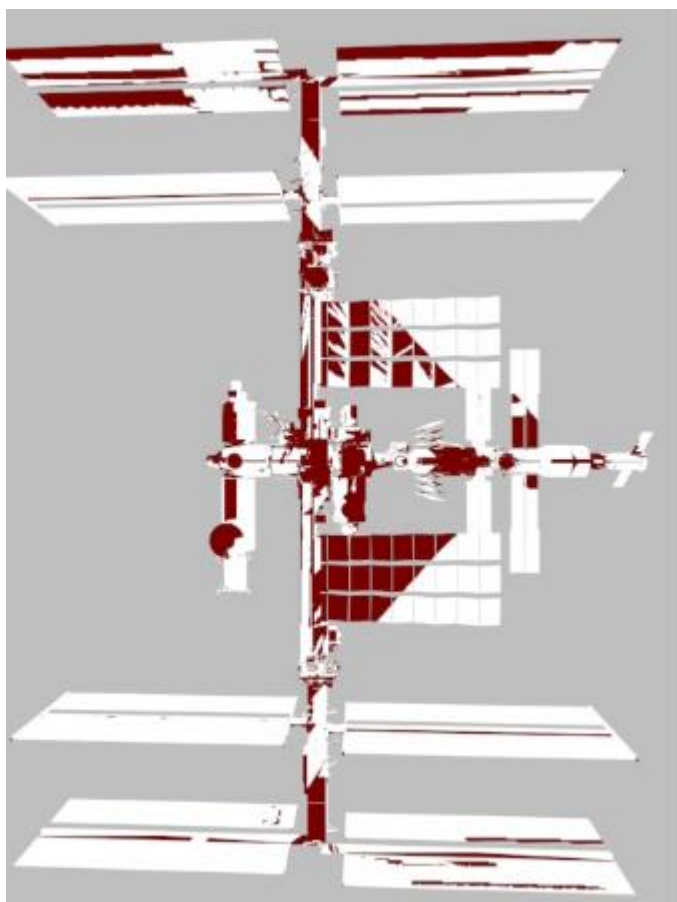
- **Regular, periodic inspection is limited to line-of-sight views**
- **Limited available IVA crew time**
 - **General ISS periodic inspection is lower priority to science and maintenance**
- **Scheduling ground controlled imagery surveys with ETVCGs is not an issue, but it is low resolution and there are significant blind spots.**
- **Complex robotics and EVA planning**
- **Limited and lack of suitable technology on-orbit (resolution, penetration)**
 - **Few inspection requirements agreed to – we only buy/fly what we can prove we need ahead of time.**
 - **Limited Access – internally and externally**
 - **Observable MMOD surface damage is not indicative of damage underneath.**



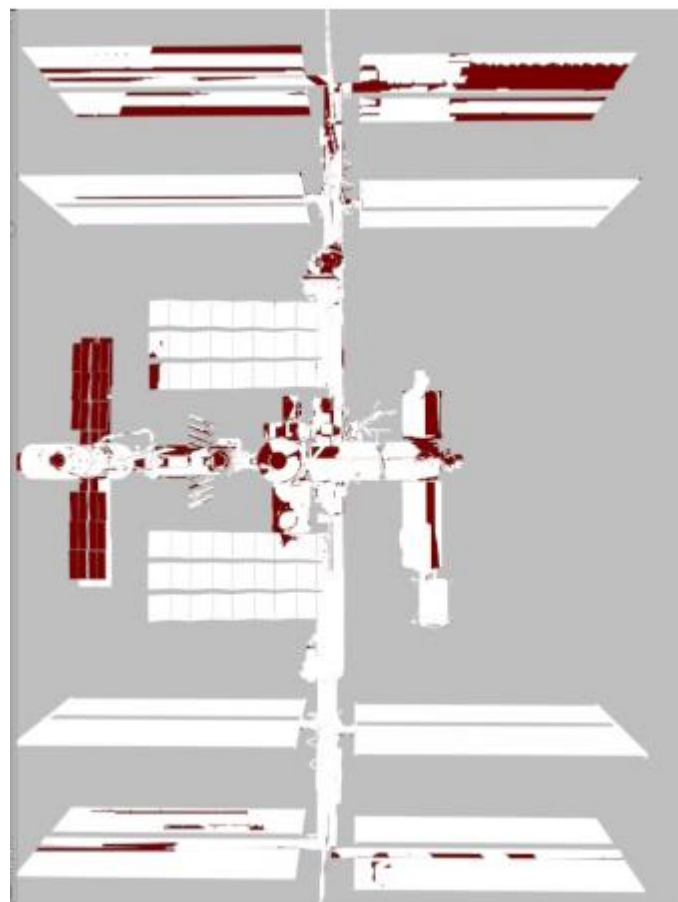
ETVCG & JEM cameras and Windows Viewing Coverage



Brown shading shows window “blind spots”



Viewing from above



Viewing from below



ISS Visual Inspection Technology Needs



- **Fill in Blind-Spots and areas of low resolution resulting from fixed camera locations and windows**
- **Replace Shuttle fly-around imagery set which provided general ISS periodic inspection and views of overall ISS configuration**
- **Upgraded camera capabilities**
 - Better resolution – lack a good close-up, inspection capability
 - Color, Stereo, 3D vision for better depth determination
 - Penetrating sensor technology (e.g. backscatter x-ray)